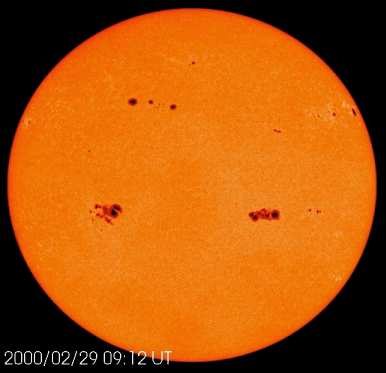
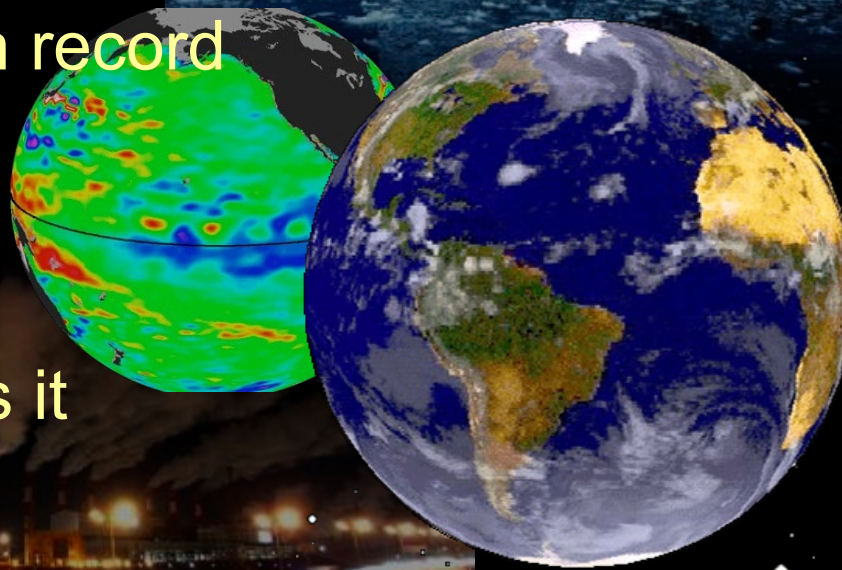


Navigating the Causes of Modern Climate Change

Judith Lean

Laboratory for Atmospheric and Space Physics, UC Boulder
Space Science Division, Naval Research Laboratory, Emeritus

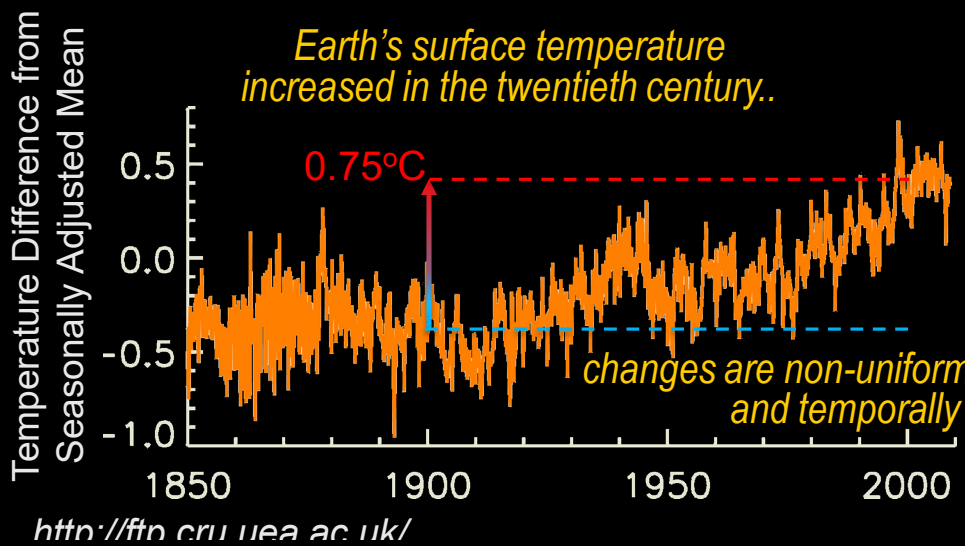
- The early 21st Century global warming "pause"
  - *is climate change a hoax?*
  - *are observations believable?*
- 2016-2019 - "hottest" years on record
  - *what does this (really) mean?*
- Climate Models
  - *are they believable?*
- If global warming is real, why is it so cold?
  - *radiation vs dynamics*
- What to expect in the future

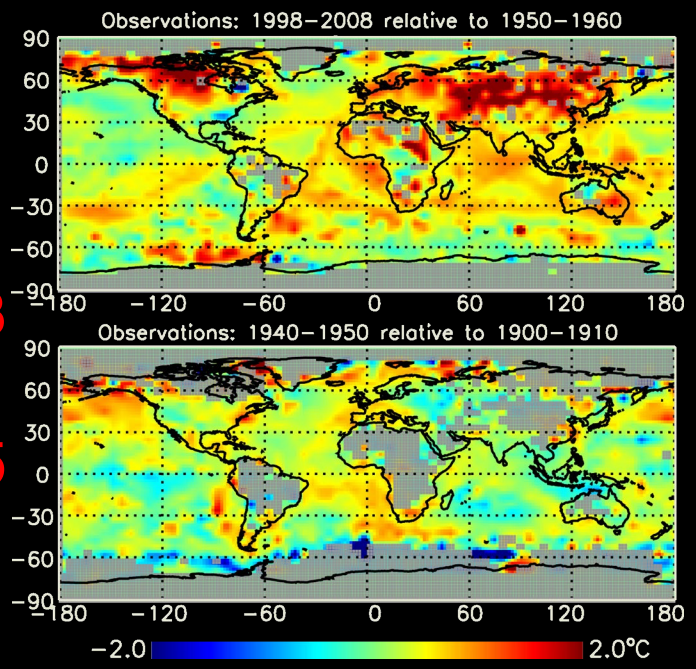


Tucson Jan 2020

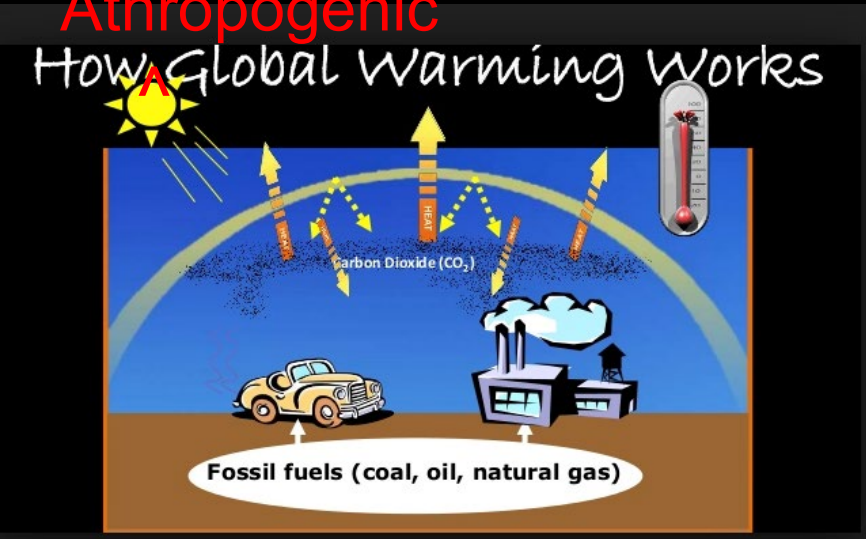
Supported by NASA

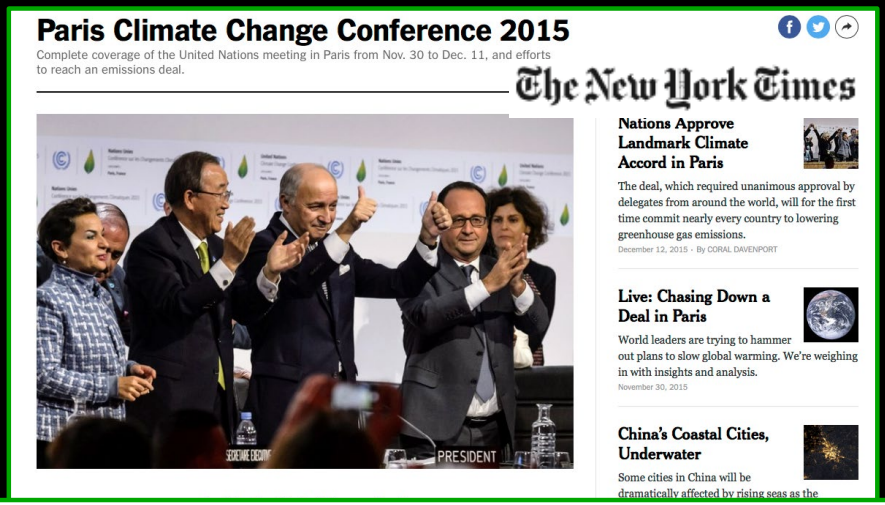
Surface Temperature Records & Proxies in the Past Century Indicate that Earth is Warming





Athropogenic

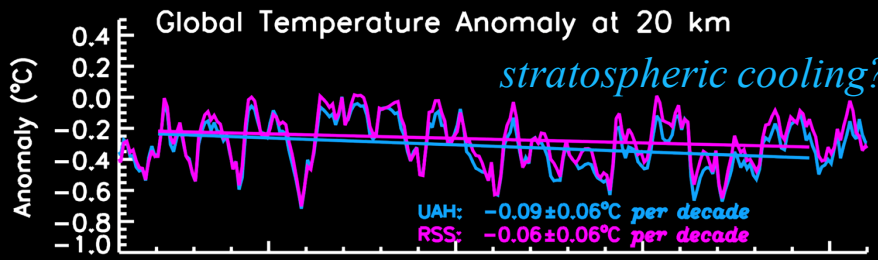


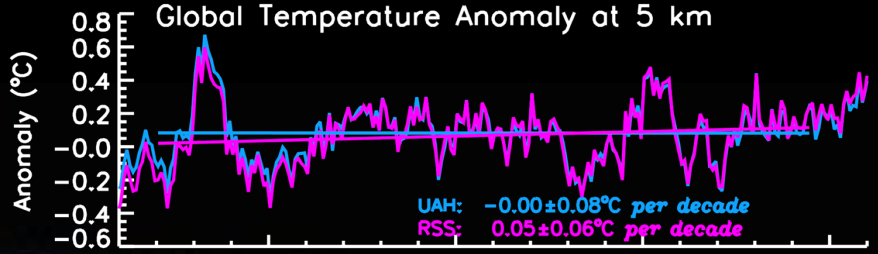


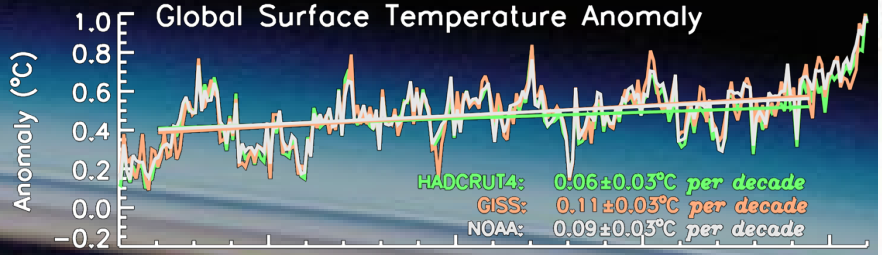
BUT….Observations of Surface & Atmospheric Temperature show Minimal Global Warming in the Past Twenty Years …

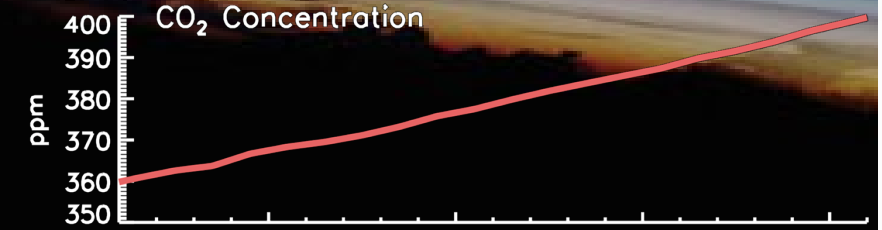
even as greenhouse gas concentrations continued to increase

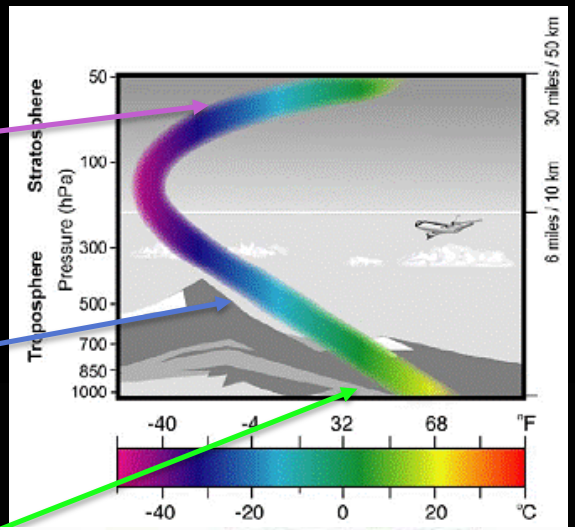
Temperature Difference from Seasonally Adjusted Mean





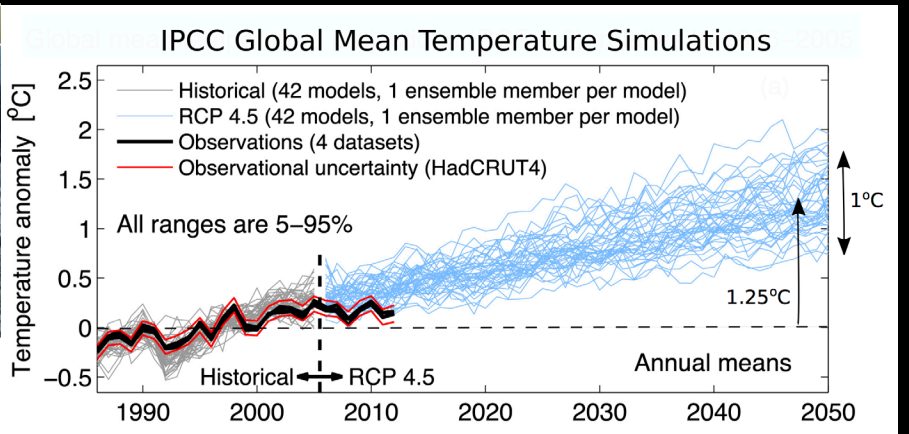






IPCC Invoked a "Global Warming Hiatus" to Explain Climate Change in the Past Twenty Years

Surface Warming "Pause"



Message:

Scientist don't know why global surface temperature did not increase in the past 15 years.

The Implication of "missing mechanisms" exacerbated public and policy makers lack of confidence in climate scientists and climate models.

Proposed Causes of the Pause

Lean, WIRES, 2018

IPCC's imprimatur of a global warming "hiatus" precipitated a plethora of research seeking to identify mechanisms that might influence climate on decadal time scales but that current physical climate models supposedly neglect…..

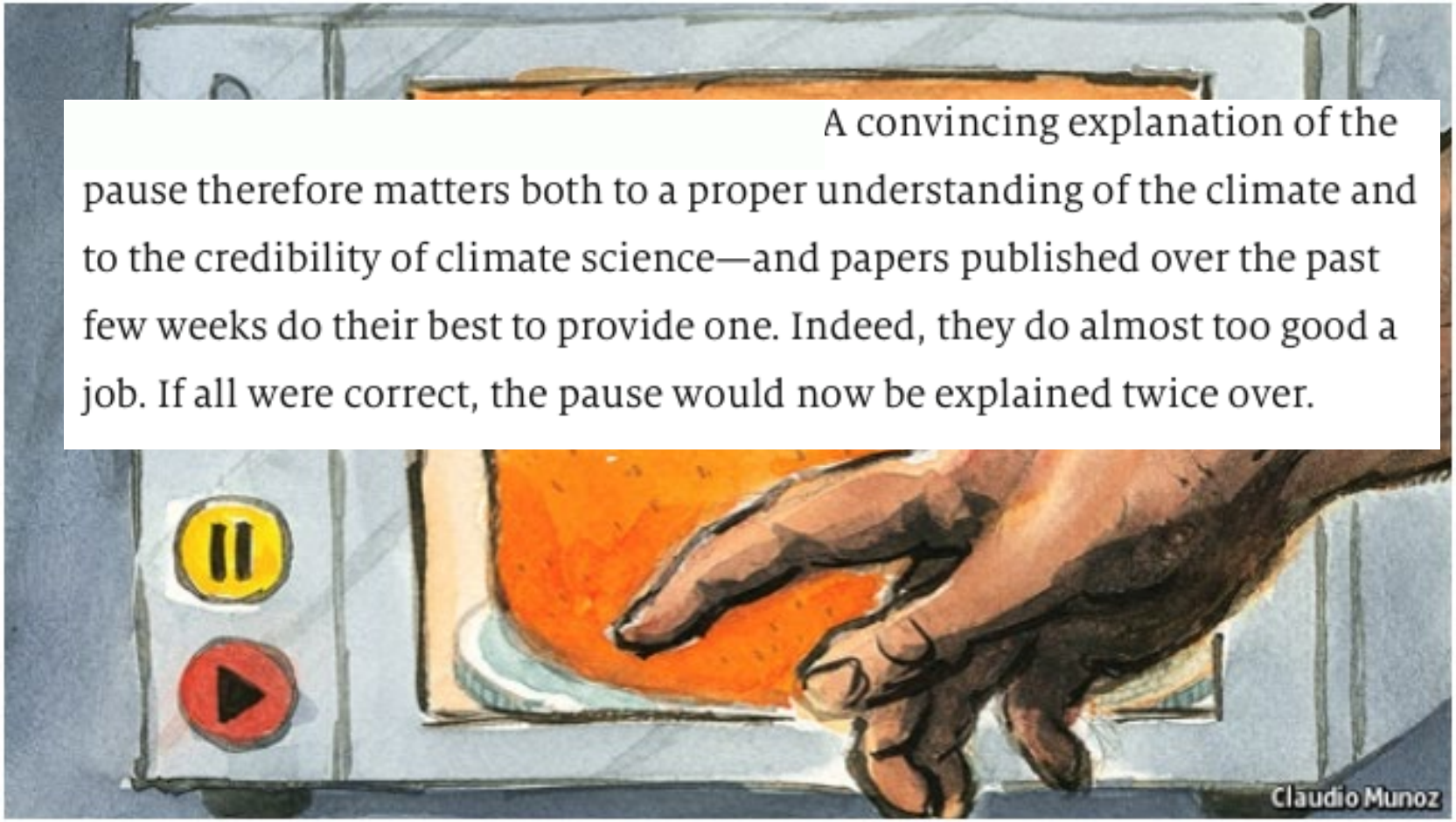
- "missing heat" that had not warmed the planet was "hiding in the oceans" *(Meehl et al., 2011).*
  - *anthropogenic forcing imparted significant energy to the Earth during the 21st century ... it had to go somewhere*
- "missing heat found" in the Pacific region, a result of "ENSO-like" natural variability (*Kosaka & Xie, 2013*).
- missing internal variability
  - *decadal-scale Pacific warming a result of IPO, the Interdecadal Pacific Oscillation (Fyfe et al., 2016; NASEM, 2016)*
- missing or incorrect radiative forcings
  - *global cooling by industrial aerosols from China's coal burning (Kaufmann et al., 2011)*
  - *cooling by "background" volcanic aerosols (Ridley et al., 2014; Schwartz et al., 2014; Solomon et al., 2011)*
  - *cooling from anomalously low solar irradiance (Huber & Knutti, 2014; Schmidt, Shindell, & Tsigaridis, 2014).*

Global warming

Who pressed the pause button?

The Economist
6 March 2014

The slowdown in rising temperatures over the past 15 years goes from being unexplained to overexplained



A convincing explanation of the pause therefore matters both to a proper understanding of the climate and to the credibility of climate science—and papers published over the past few weeks do their best to provide one. Indeed, they do almost too good a job. If all were correct, the pause would now be explained twice over.

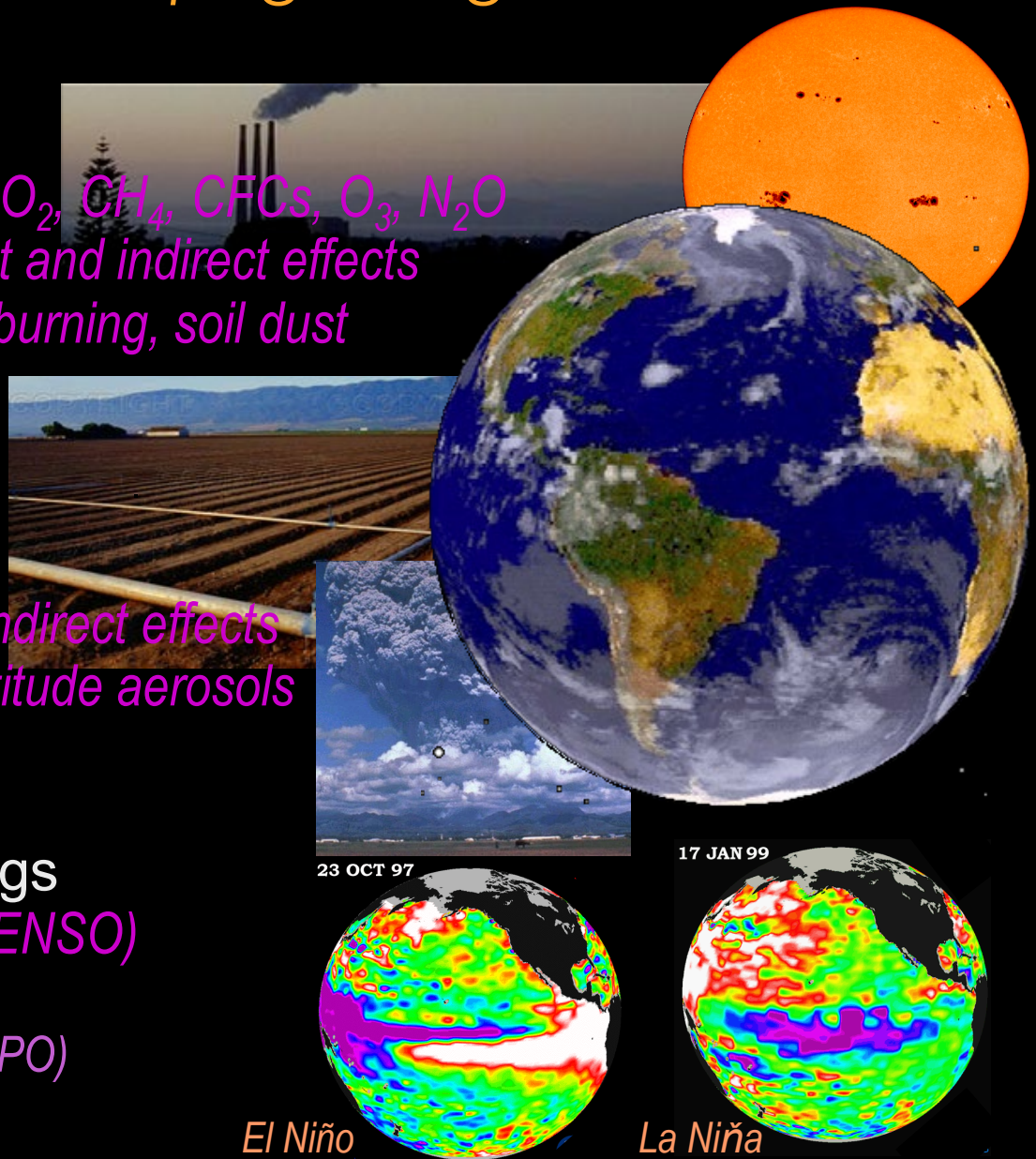
There are Many Causes of Global Change
… *not just anthropogenic gases*

Anthropogenic Gases
- atmospheric GH gases - *CO_2, CH_4, CFCs, O_3, N_2O*
- low altitude aerosols - *direct and indirect effects of soot, sulfate, carbon, biomass burning, soil dust*

Land Cover Changes

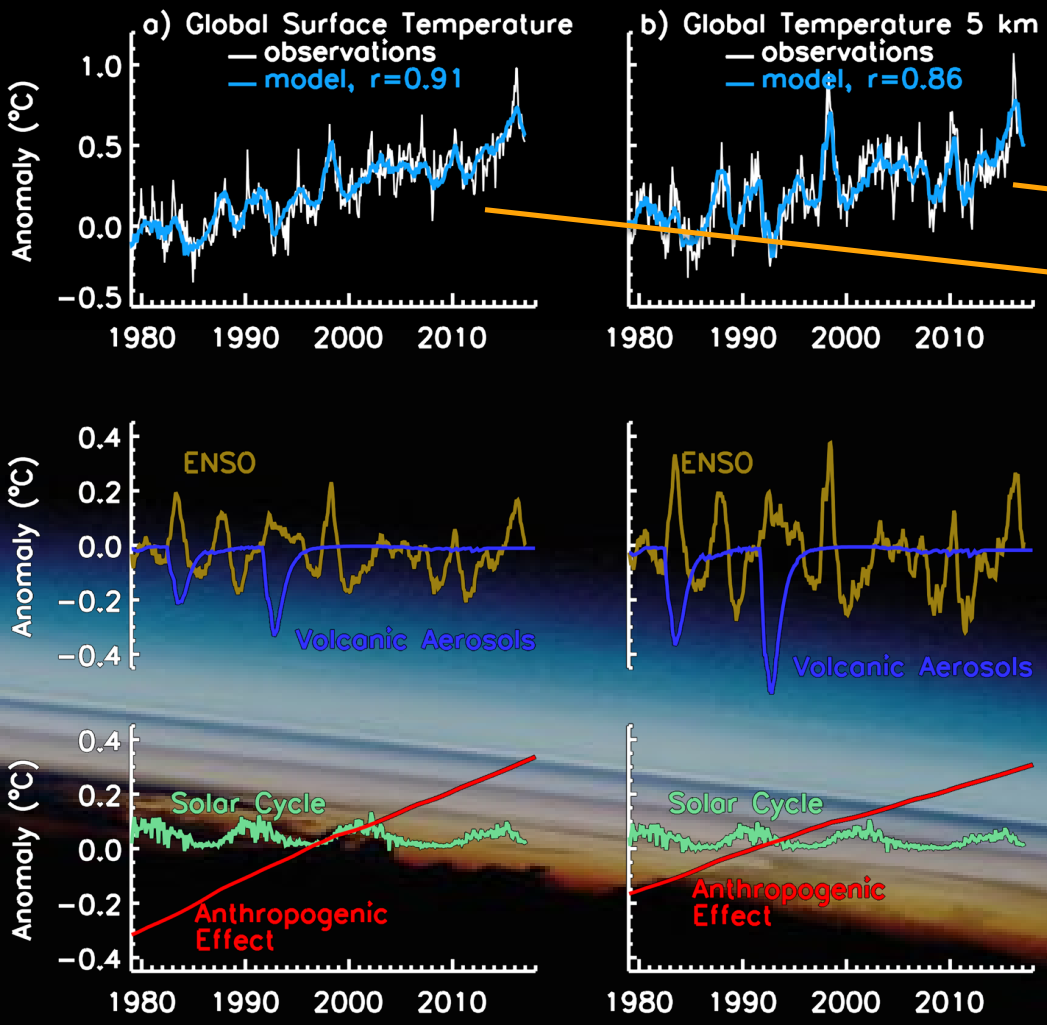
Natural Forcings
- solar variability - *direct and indirect effects*
- volcanic eruptions – *high altitude aerosols*

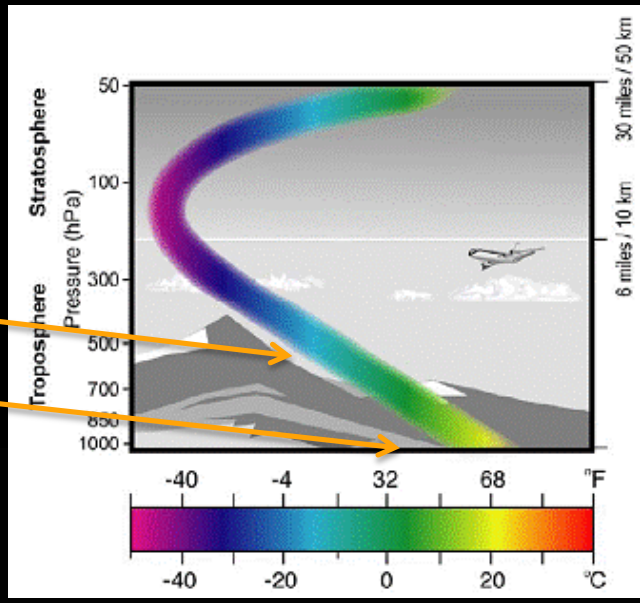
Internal Oscillations
- atmosphere-ocean couplings
  - *El Niño Southern Oscillation (ENSO)*
  - *North Atlantic Oscillation (NAO)*
  - *Pacific Decadal Oscillation (PDO, IPO)*
  - *Quasi Biennial Oscillation (QBO)*



Decoding the Observations: Troposphere

Surface Temperature Temperature at 5 km

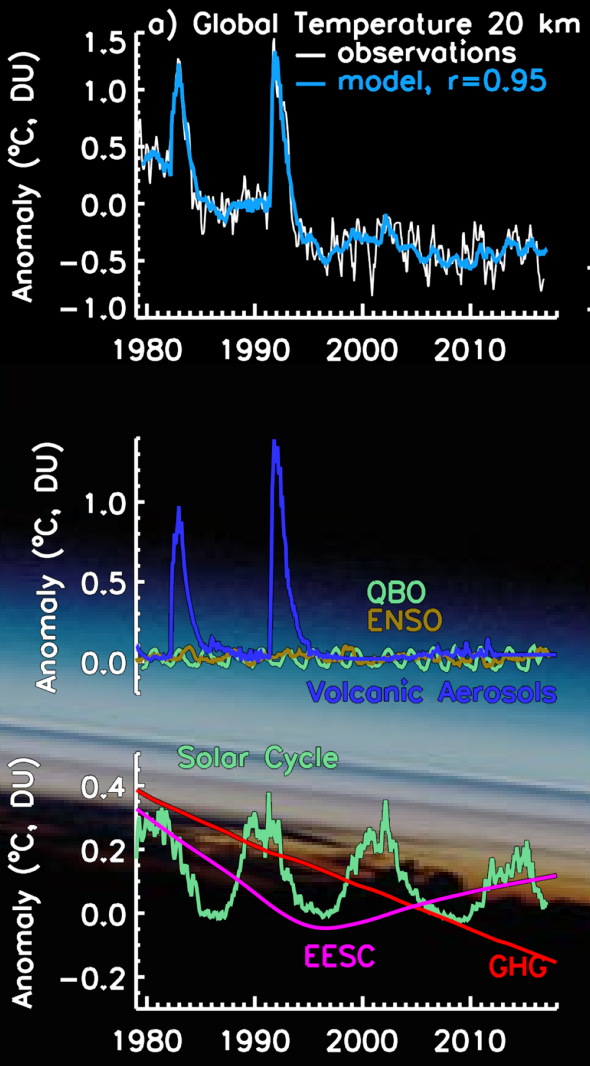




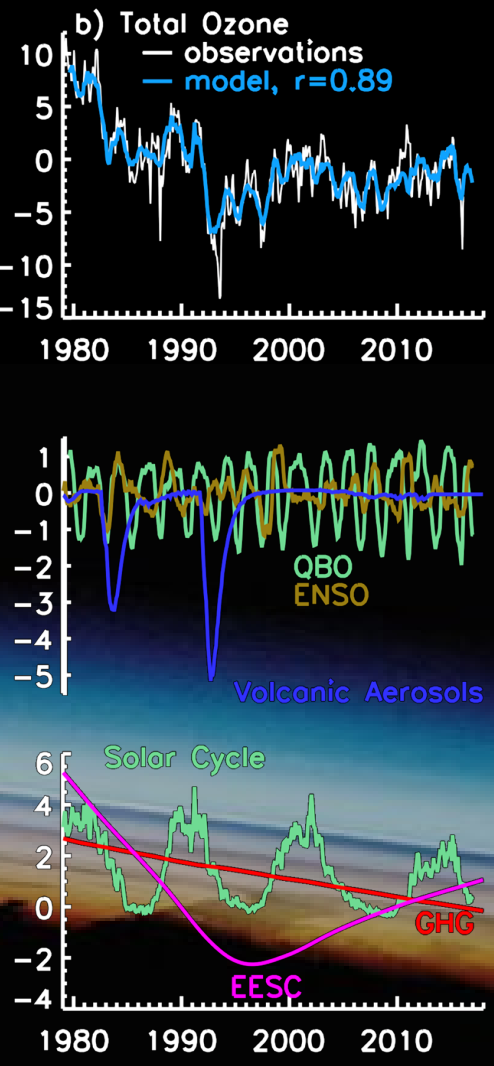
A lack of global warming does not mean the absence of warming from anthropogenic influences.

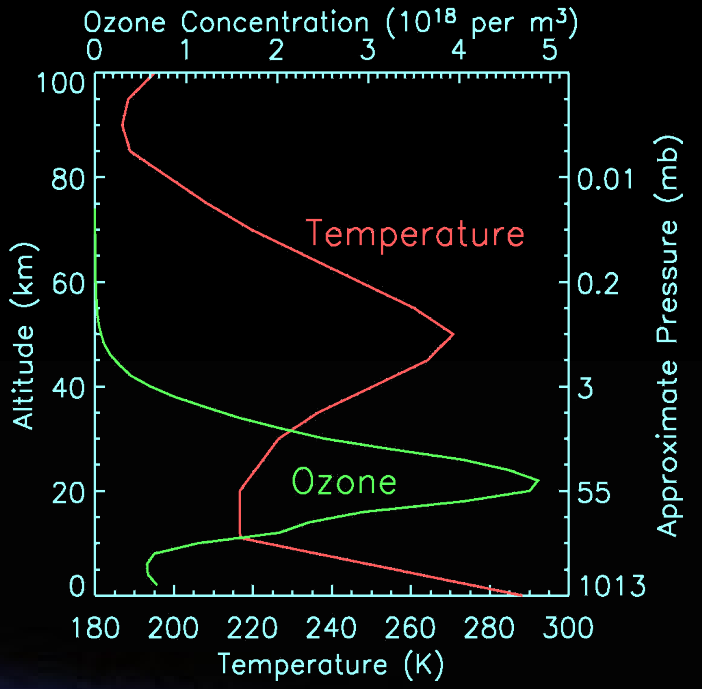
Decoding the Observations: Stratosphere

Temperature at 20 km

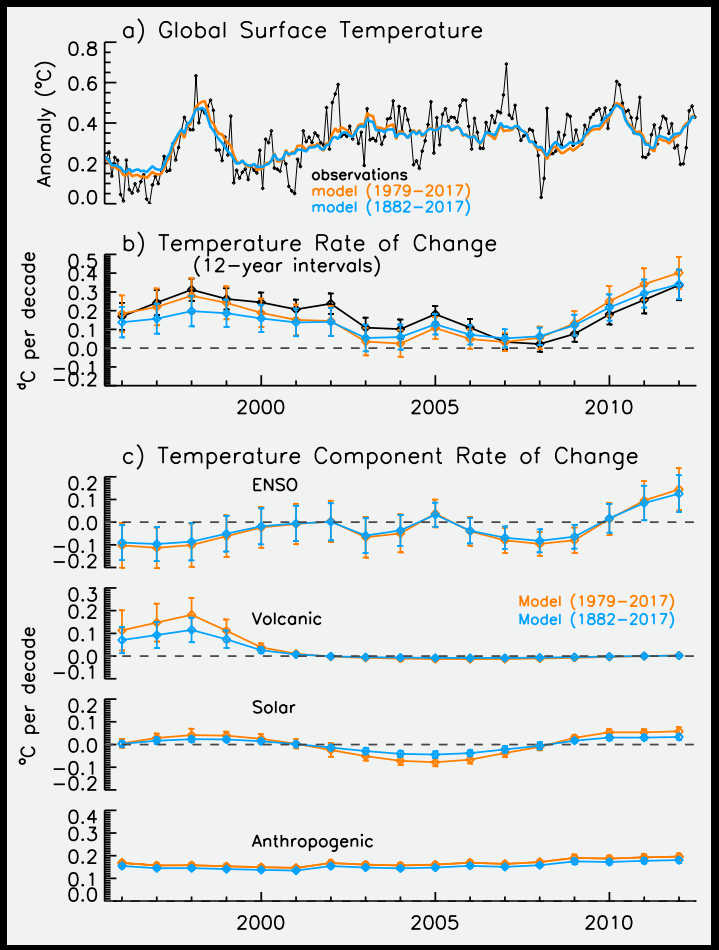


Global Total Ozone





Anthropogenic gases destroy ozone and cool the atmosphere above 20 km.



Lean, WIRES, 2018

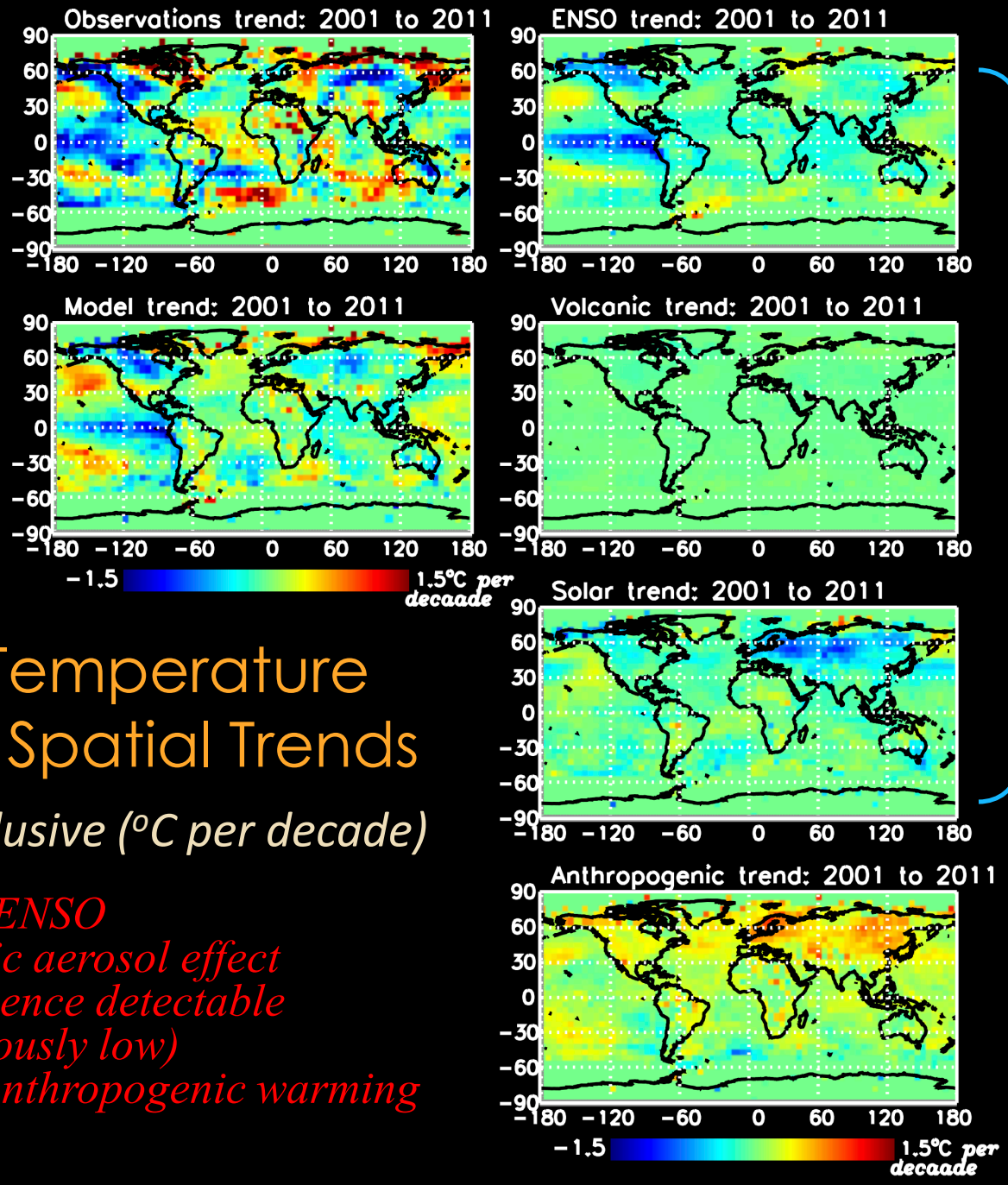
Causes of the "Pause": The Numbers

... the mitigation of (ongoing) anthropogenic warming by cooling from natural influences, predominantly La Niña conditions and a net solar irradiance decline

2001 to 2011 inclusive

°C per decade (±1σ)

		Surface	Atmosphere 5 km
Observations	*minimal trend*	0.04±0.05	-0.06±0.09
Model	*minimal trend*	0.00±0.05	-0.08±0.09
Anthropogenic	*warming*	0.15	0.11
ENSO	*cooling*	-0.09	-0.12
Solar	*cooling*	-0.05	-0.05
Volcanic	*cooling*	-0.01	-0.02



Observations

net minimal trend

Model

ENSO

Volcanic Aerosols

net cooling

Solar Irradiance Cycle

Anthro-pogenic Influence

warming

Inventory: Temperature Component Spatial Trends

2001 to 2011 inclusive (°C per decade)

... "ENSO like" = ENSO
... minimal volcanic aerosol effect
... solar cycle influence detectable (not anomalously low)
... no "pause" in anthropogenic warming

Did China's coal burning REALLY offset global warming in the past decade? (No)

"*The new study (Kaufmann et al., PNAS, 2011) shows that while greenhouse gas emissions continue to rise, their warming effect on the climate was offset by the cooling produced by the rise in sulphur pollution*."
http://environmentalresearchweb.org/

Cooling is insufficient to offset warming by greenhouse gases

5 July 2011 Last updated at 04:16 ET

Global warming lull down to China's coal growth

By Richard Black
Environment correspondent, BBC News

The lull in global warming from 1998 to 2008 was mainly caused by a sharp rise in China's coal use, a study suggests.

The absence of a temperature rise over that decade is often used by "climate sceptics" as grounds for denying the existence of man-made global warming.

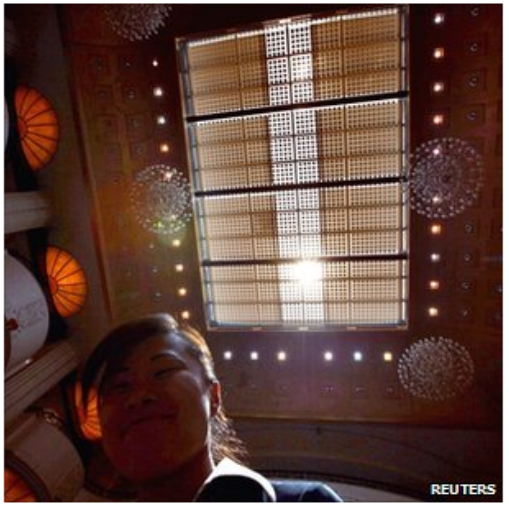
But the new study, in **Proceedings of the National Academy of Sciences**, concludes that smog from the extra coal acted to mask greenhouse warming.

China's coal use doubled 2002-2007, according to US government figures.

Although burning the coal produced more warming carbon dioxide, it also put more tiny sulphate aerosol particles into the atmosphere which cool the planet by reflecting solar energy back into space.

The researchers conclude that declining solar activity over the period and an overall change from El Nino to La Nina conditions in the Pacific Ocean also contributed to the temperature plateau.

Lead researcher Robert Kaufmann from Boston University, whose research interests span climate change and world oil markets, said the study was inspired by "sceptical" questioning.



Solar power is coming to China - but coal-burning grew amazingly quickly a few years back

Related Stories

Solar predictions bring heat and light
Solar surprise for climate issue
Climate science, from Bali to Copenhagen

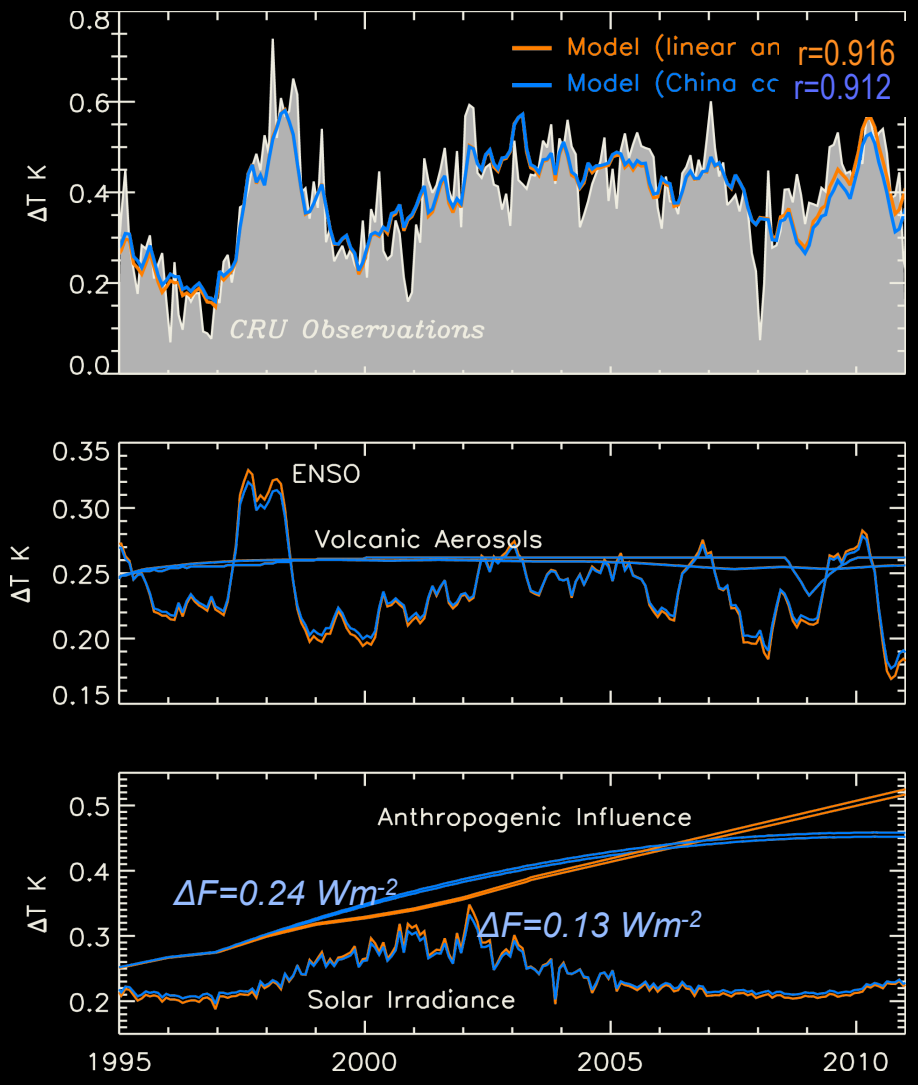
Did "background" stratospheric aerosols offset global warming in the past decade (No)?

"..stratospheric aerosols increased in abundance since 2000..."

- *corresponding negative radiative forcing is -0.1 Wm^{-2}*
- *reduced global warming by 0.07°C*

Solomon et al, Science Express, 2011

BUT from empirical model…
optical depth increase from Pinatubo eruption = 0.15, ΔT=-0.3°C
optical depth increase from 2000-2010 = 0.005, ΔT=0.01°C



The end of the "pause": 2016, "Hottest Year on Record"

Technology | Mon Sep 14, 2015 9:15am EDT

Related: ENVIRONMEN

Global warming hiatus could be coming to an end: UK's Met Office

September 2015

Smoke billows from the chimneys of Belchatow Power Station, Europe's biggest coal-fired power plant, in this May 7, 2009 file photo.
REUTERS/PETER ANDREWS/FILES

Record temperatures and changes to climate patterns in the world's oceans are among signs that a global warming pause is coming to an end, Britain's Met Office said in a report on Monday.

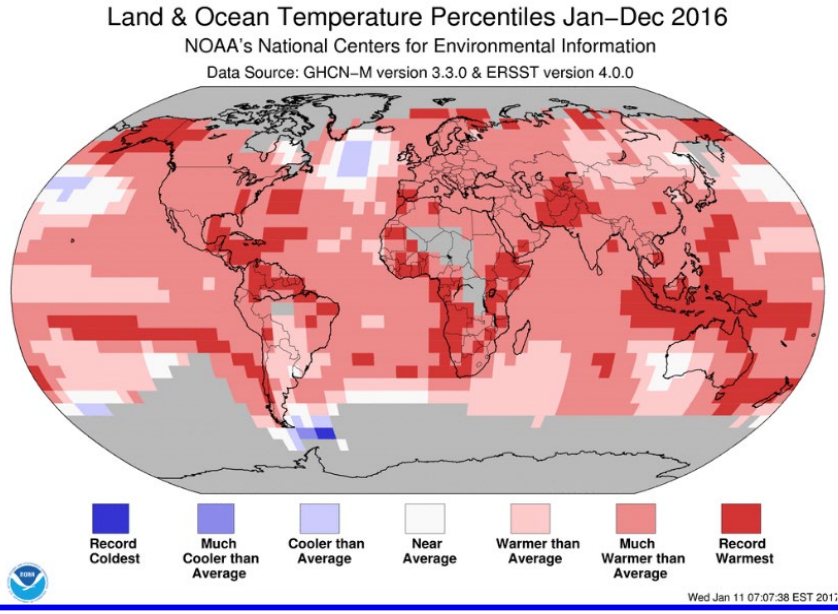
January 2017

Energy and Environment

U.S. scientists officially declare 2016 the hottest year on record. That makes three in a row.

By Chris Mooney January 18

The Washington Post
Democracy Dies in Darkness



Vivid Maps
@VividMaps
Follow

NASA: 2016 was the hottest year on record, continuing a decades-long warming trend
vividmaps.com/2017/01/nasa-2…
#ClimateChange

Hottest years in modern record

16 of the top **17** have occurred since **2000**

CNN WEATHER

Not only was this the third consecutive year to rank hotter than all previous years, it also means 16 of the 17 hottest years on record have occurred since 2000, according to NOAA. To put this in perspective, the last time we had a record cold year was 1911.

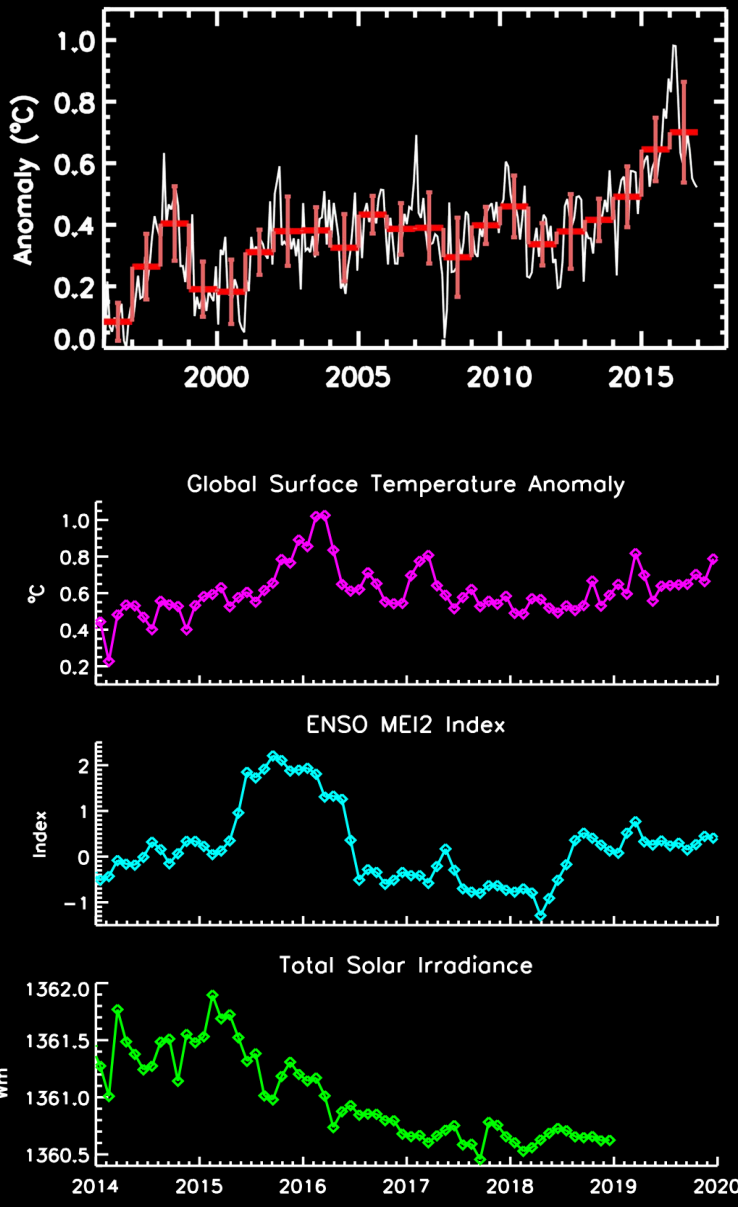
2016: "Hottest Year on Record"

….what does this (really) mean?

- ENSO warming
- sustained, ongoing, anthropogenic warming
- minimal volcanic cooling

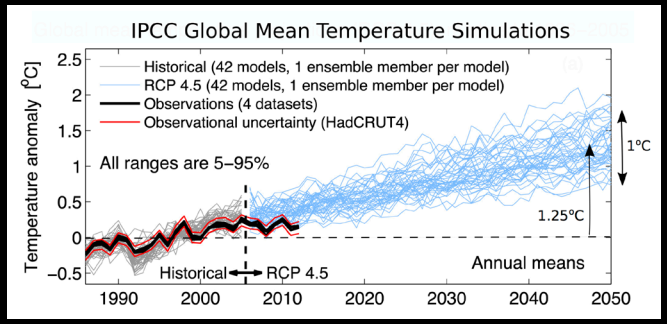
… if solar activity were at cycle minimum instead of near cycle maximum, global temperatures would have been ~0.05 cooler

…had there been a major volcanic eruption the cooling may have cancelled the ENSO-related warming



Are IPCC's Climate Models Believable?

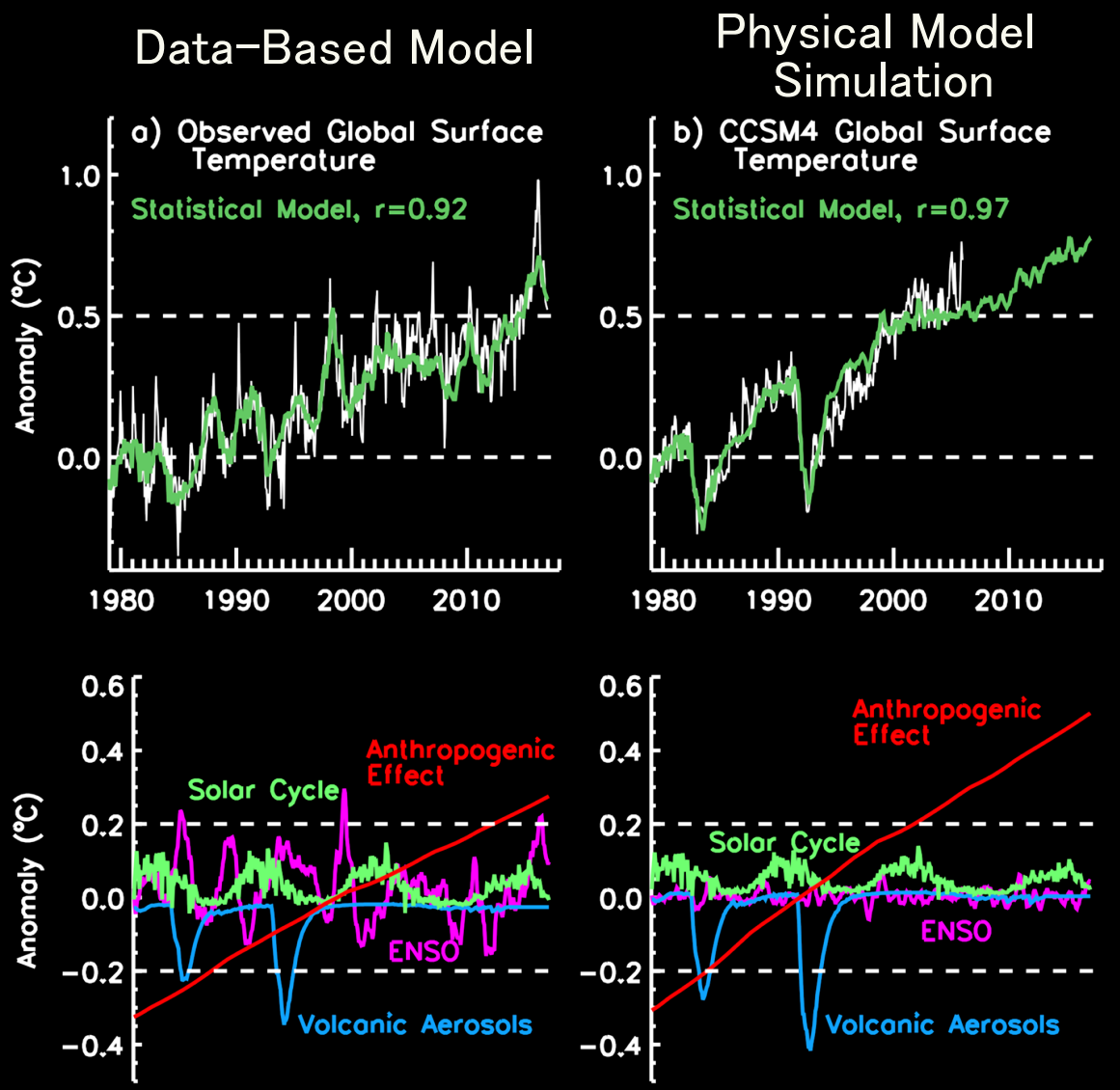
…why did they predict excess global warming in the last 20 years?



Community Climate System Model 4

- overestimates anthropogenic influence
- overestimates volcanic aerosol cooling
- does not produce realistic ENSO
- underestimates solar influence

Advancing physical model capability to better simulate natural changes will improve their decadal-scale simulations and forecasts.



Observed and Modelled Regional Surface Temperature Change Components

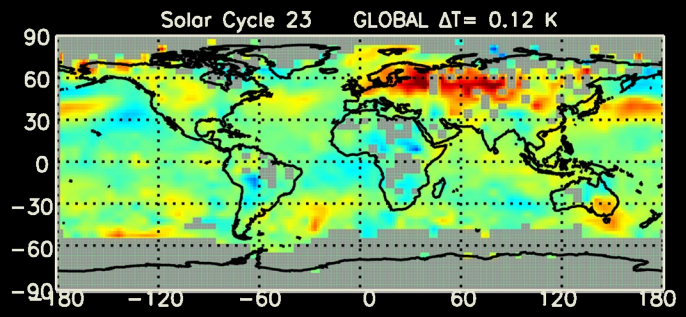
Determined Statistically from Observations

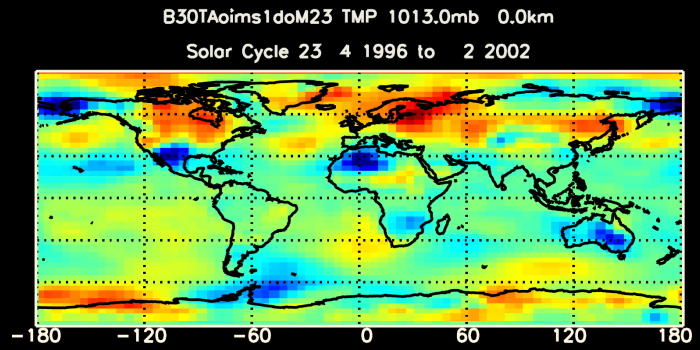
Lean and Rind, GRL, 2008

Modeled with GISS Model 3

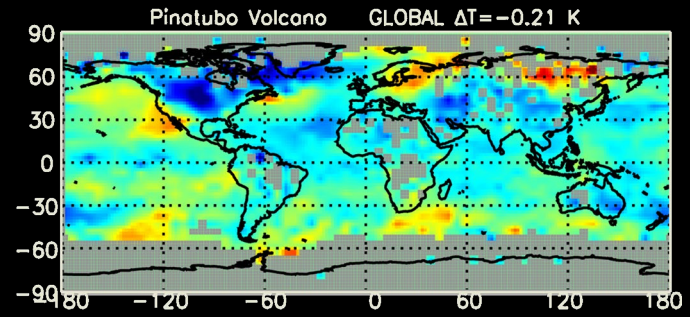
Rind et al., JGR, 2008

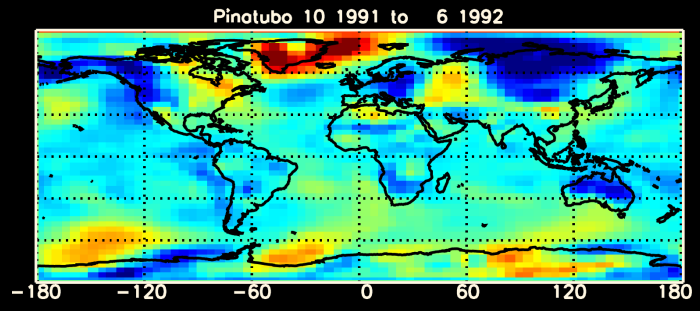
Solar Activity



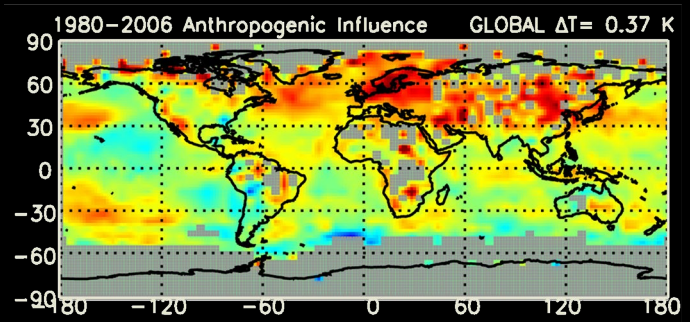


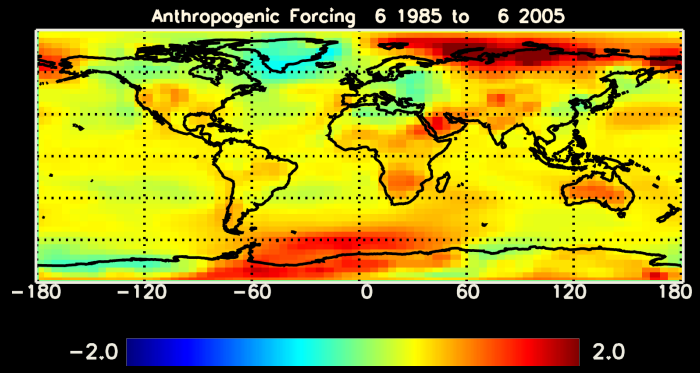
Volcanic Activity





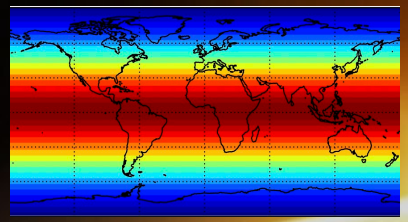
Greenhouse Gases

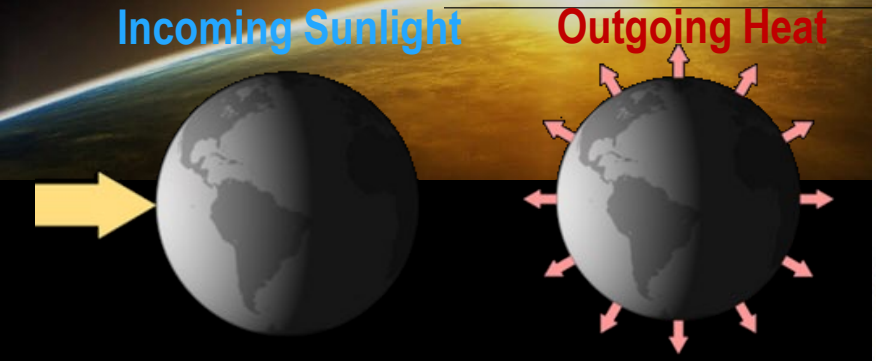




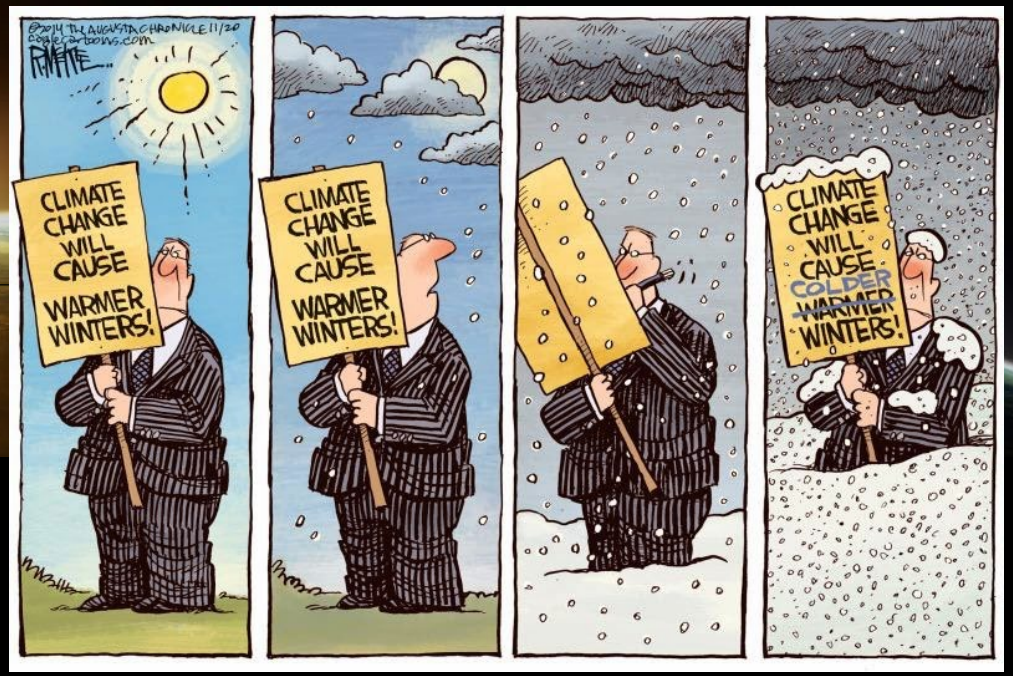
If Global Warming is Real, Why is it so Cold?

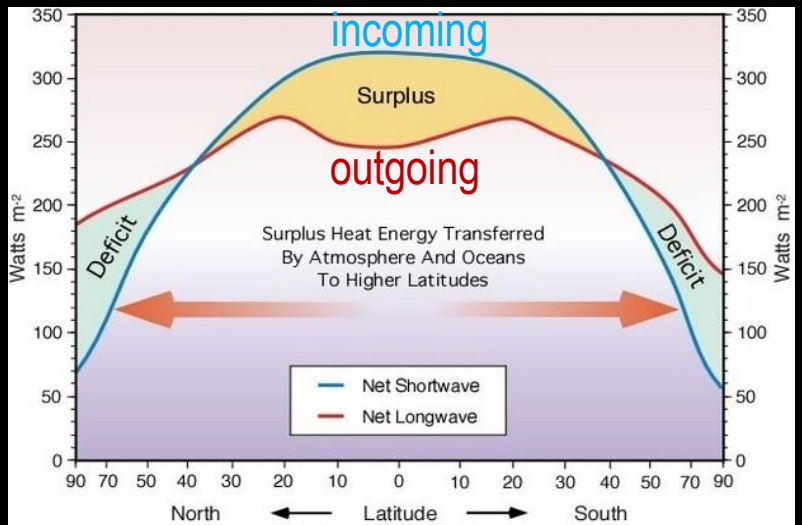
Radiation → Dynamics

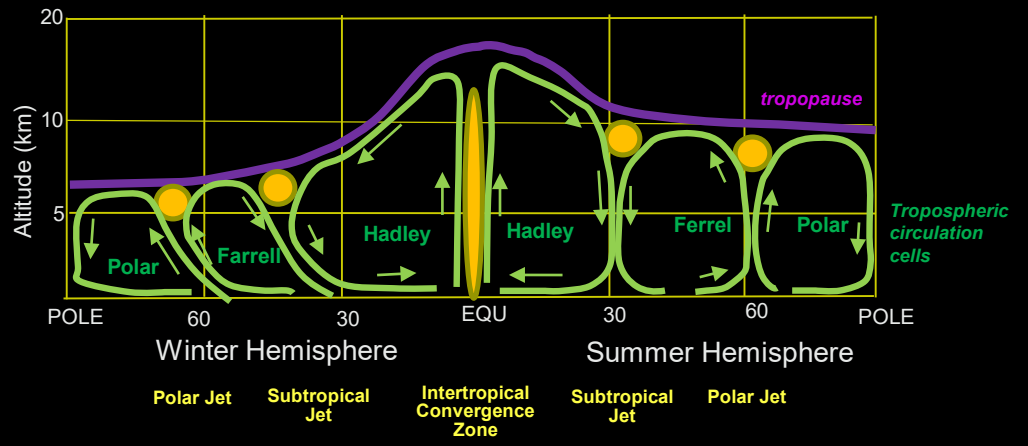




Equator-to-Pole Thermal Gradient

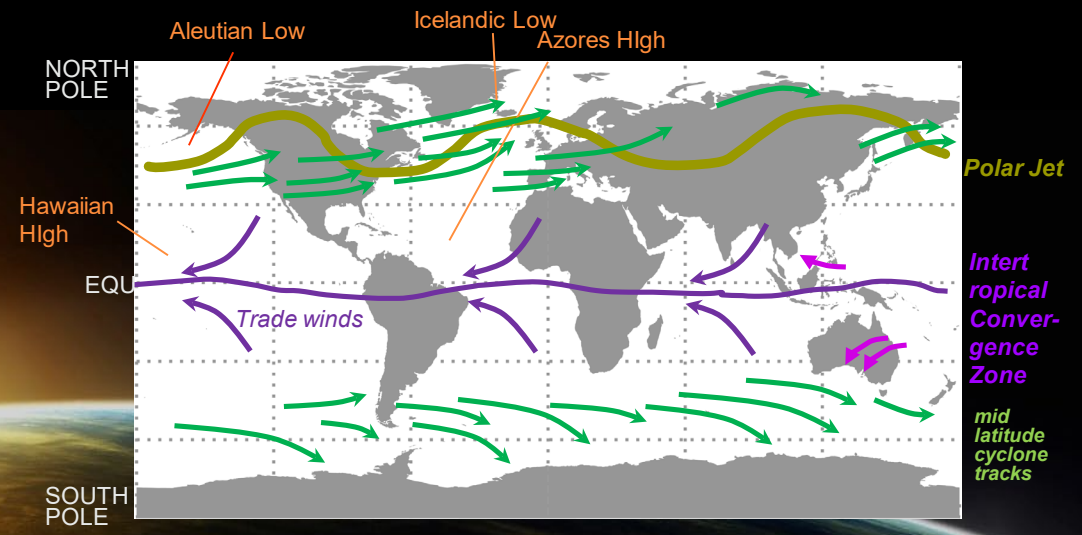


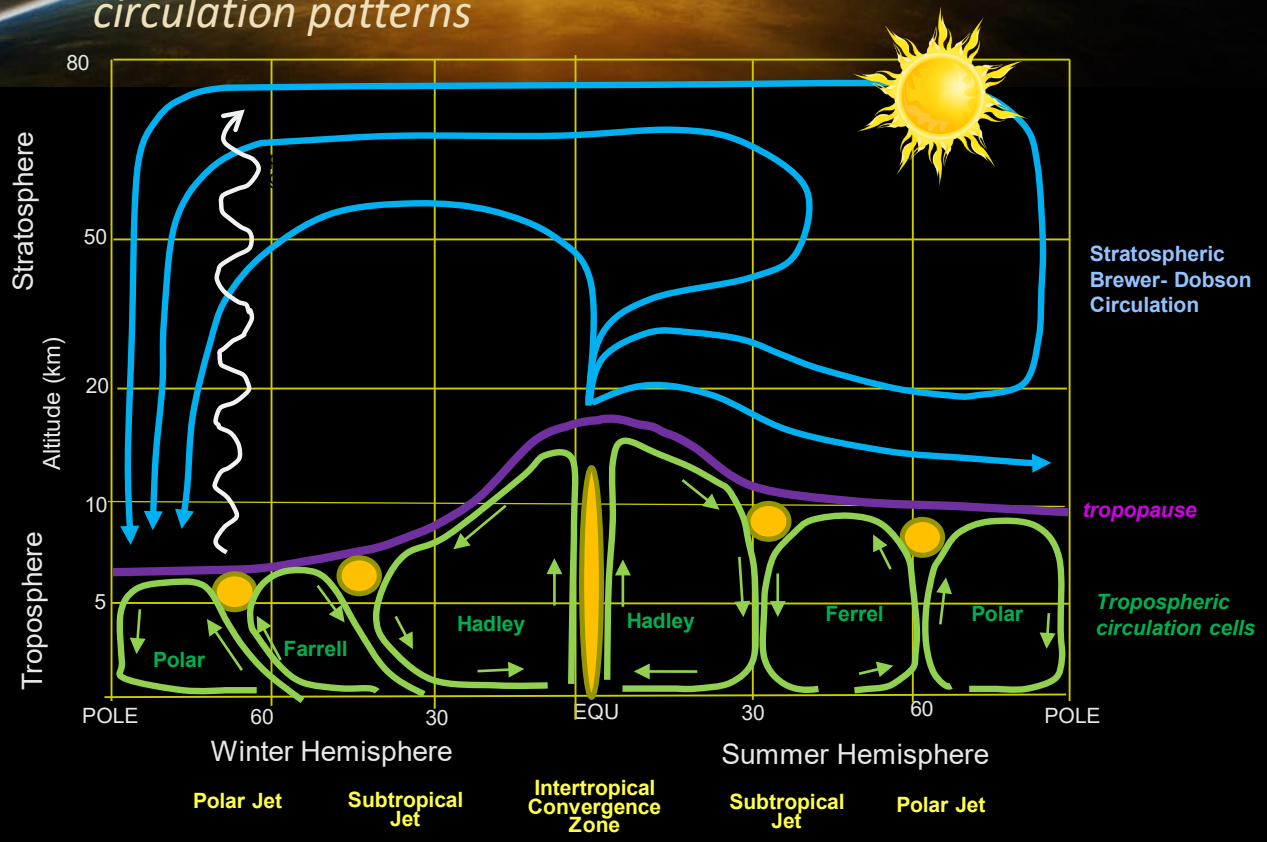




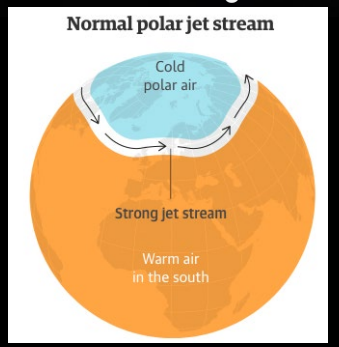
Meridional Thermal Gradient Influences Polar Vortex

dynamical motions transfer surplus energy from equator to poles and verticality between troposphere and stratosphere…establishes "normal" circulation patterns

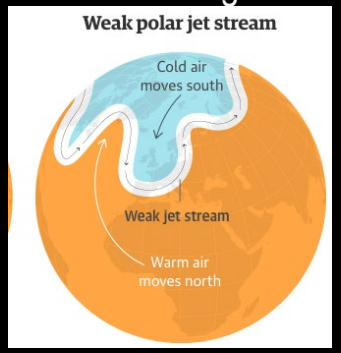




normal thermal gradient

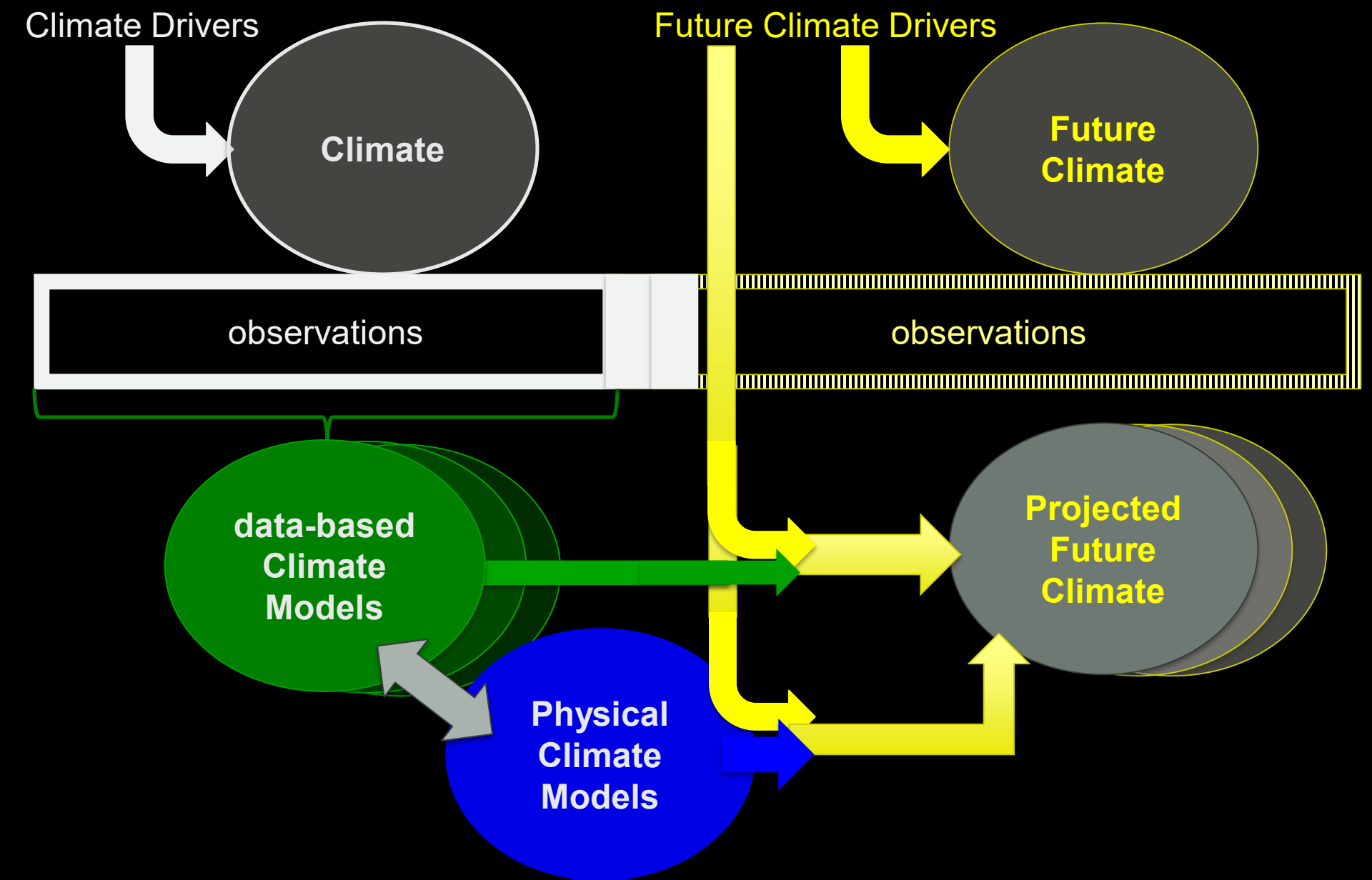


weak thermal gradient

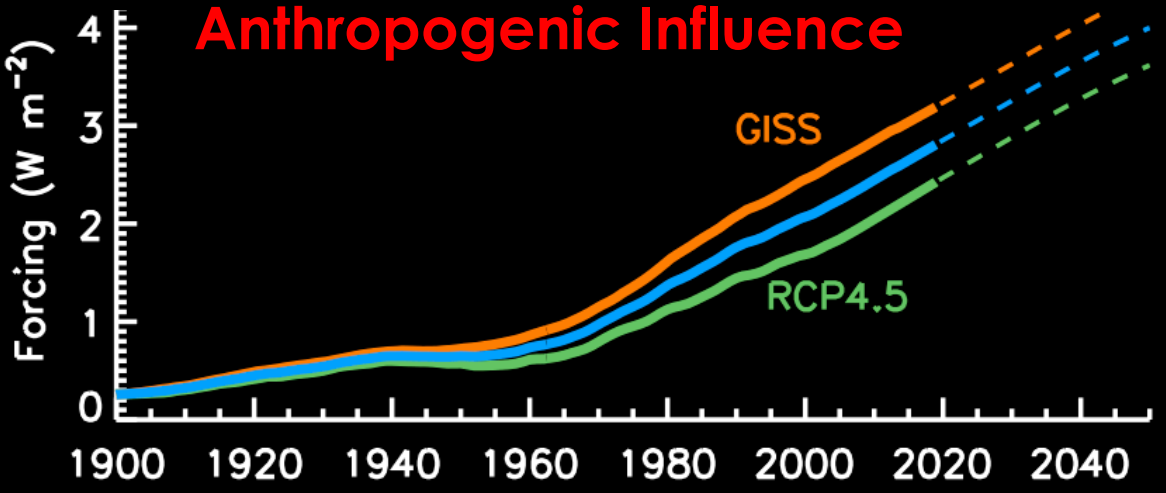


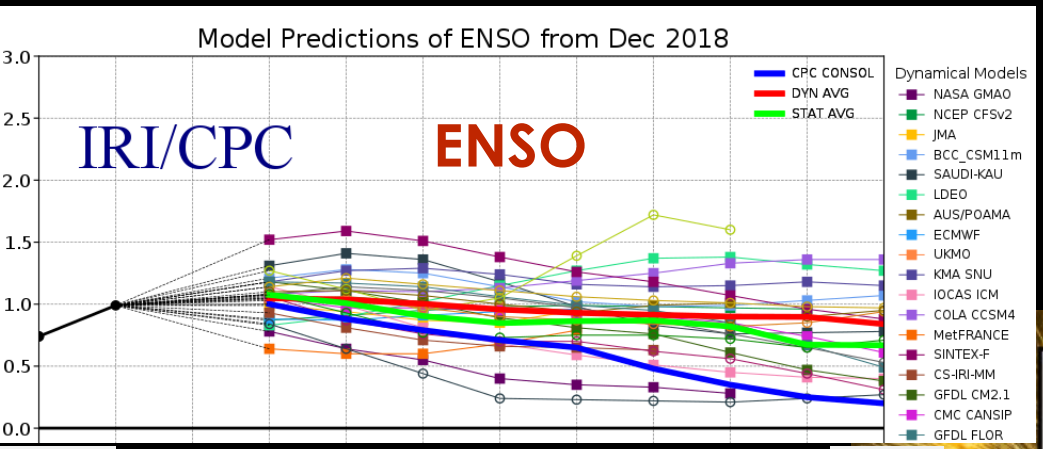
What to Expect in the Future:

making climate change projections …years to decades



Forecasting climate drivers





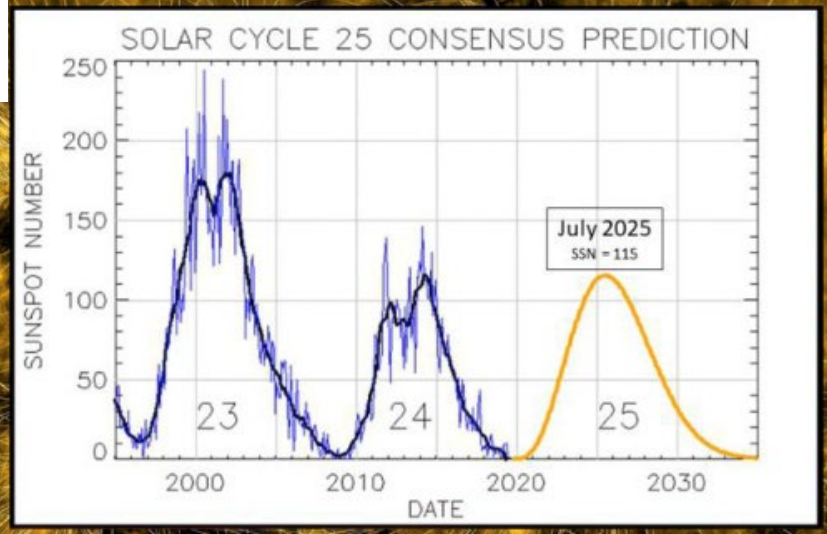
SON

https://iri.columbia.edu

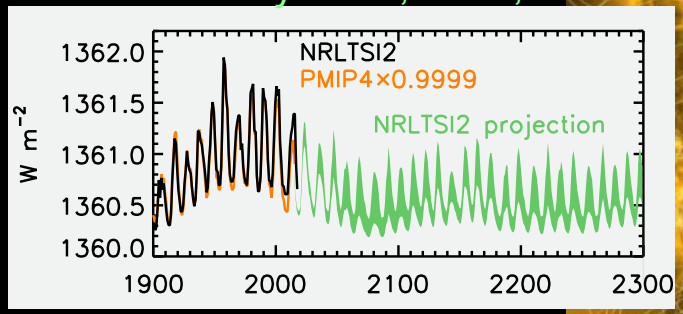
ASO

https://spaceweatherlive.com/

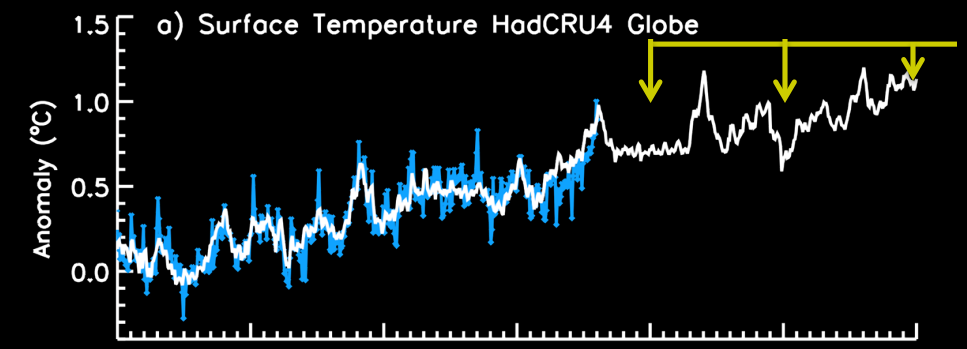
Solar Activity

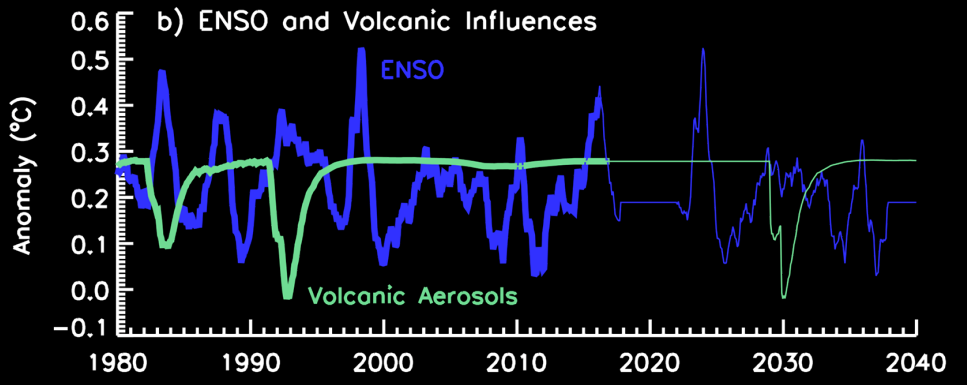


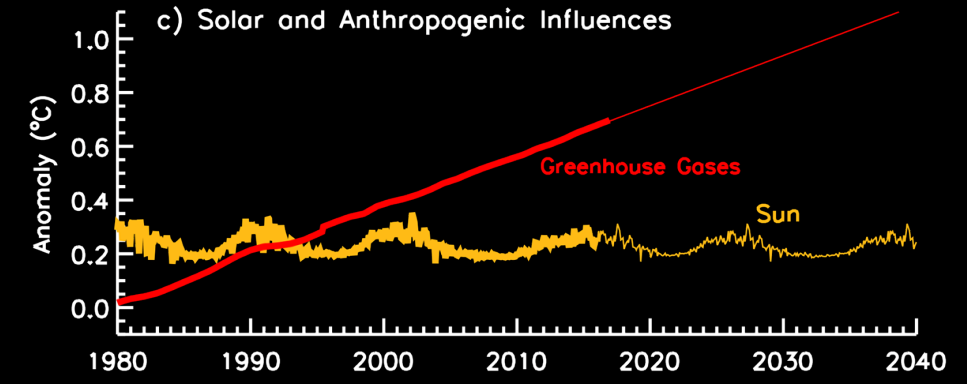
Ramaswamy et al., AMS, 2020

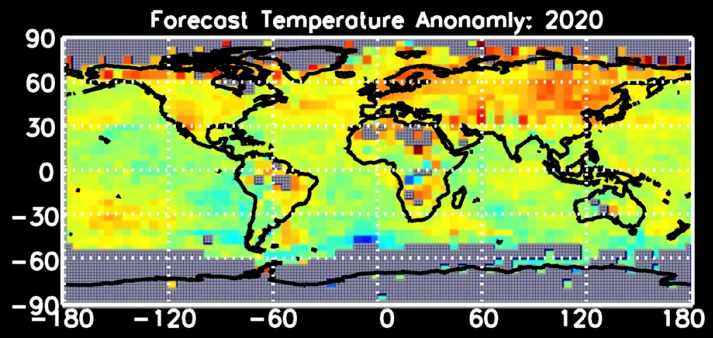


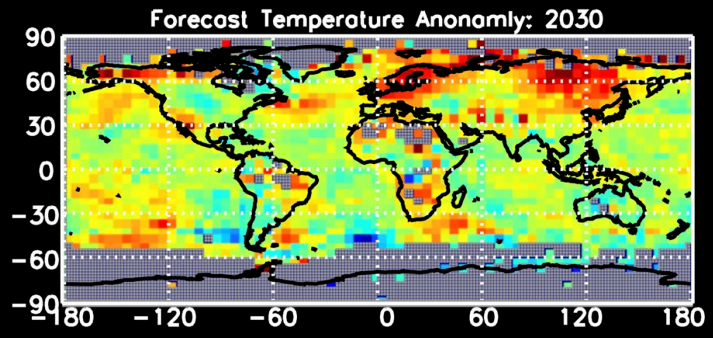
Surface temperature projections

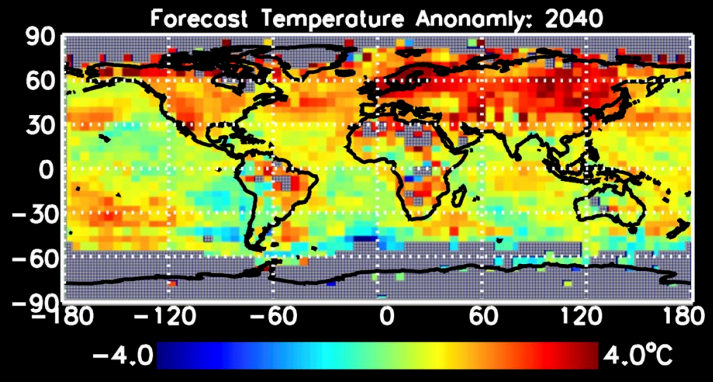








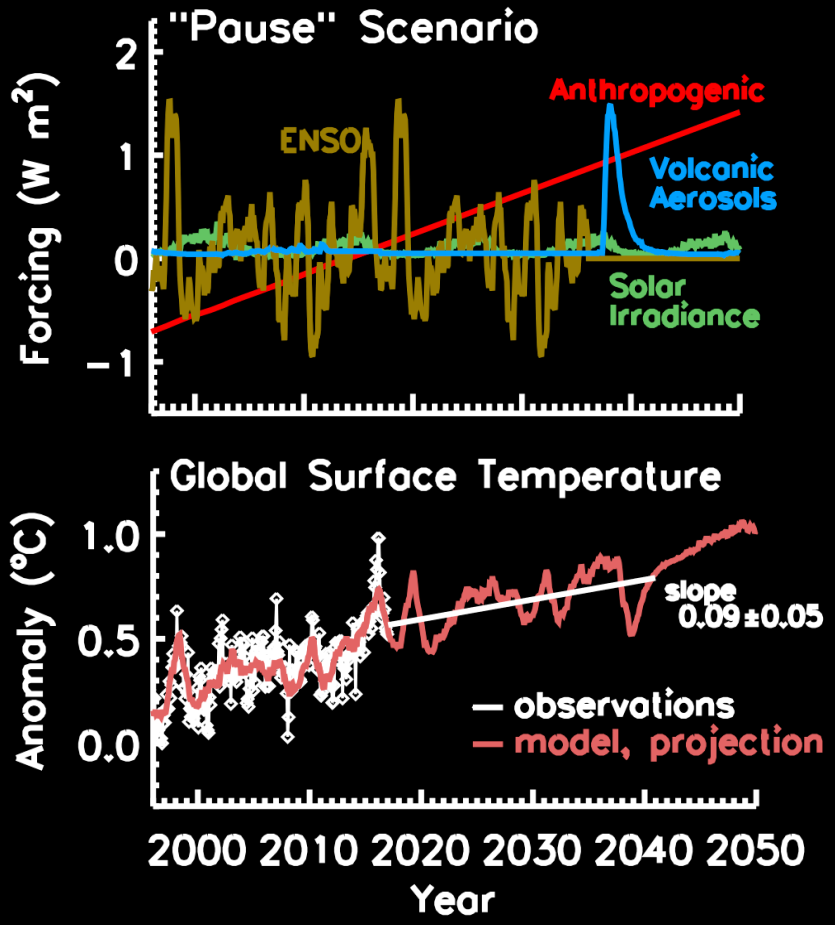




Future global surface temperature trends per decade may be…..

Minimal

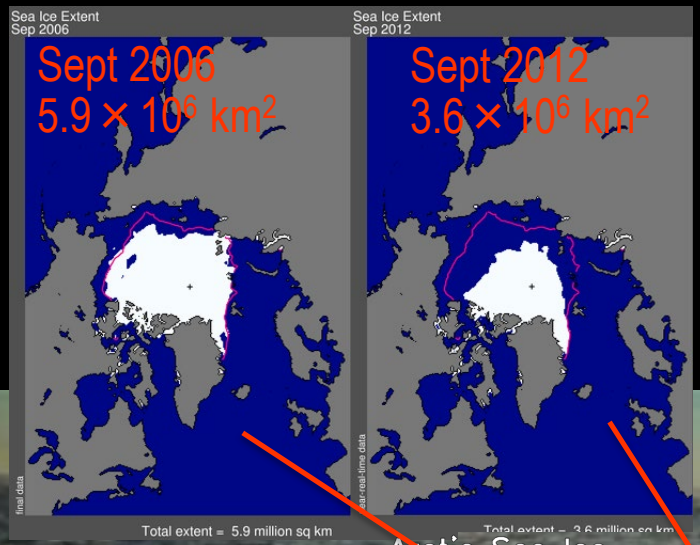
– natural influences combine to mitigate anthropogenic warming

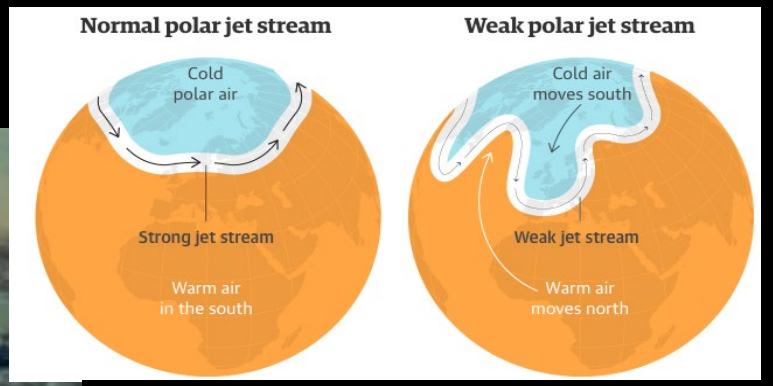


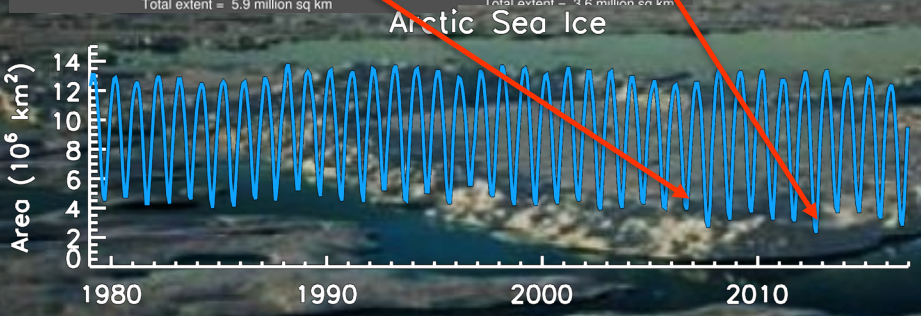
Emerging feedbacks, Tipping Points?

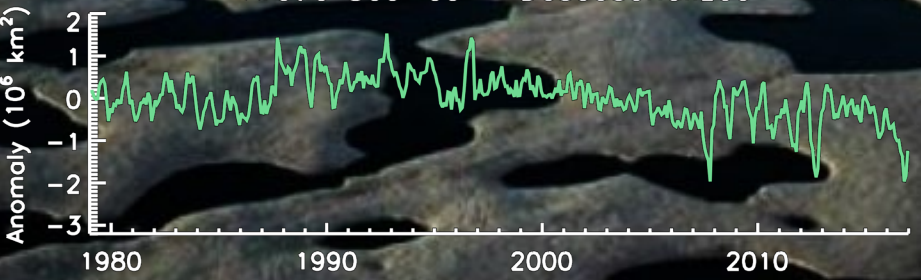
Increasing greenhouse gases

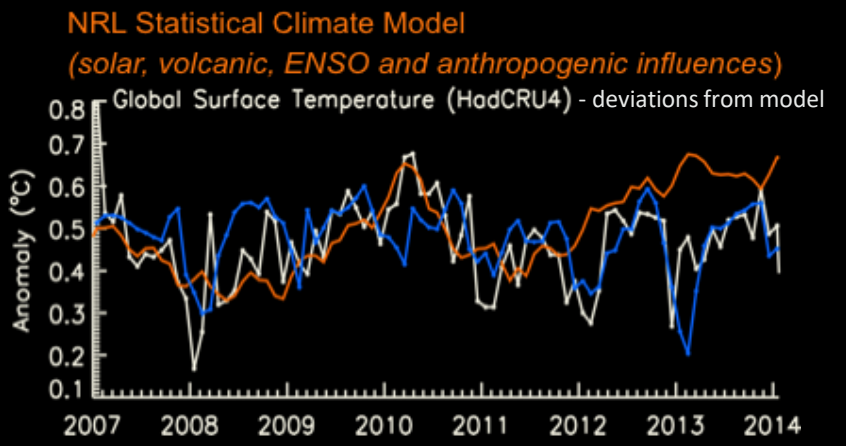
- ➔ *surface warming*
- ➔ *melting Arctic Sea Ice*
- ➔ *darker surface, increased open water*
- ➔ *increased solar absorption*
- ➔ *altered mid-to-high latitude thermal gradients*
- ➔ *altered circulation patterns*
- ➔ *NH mid latitude winter cooling*











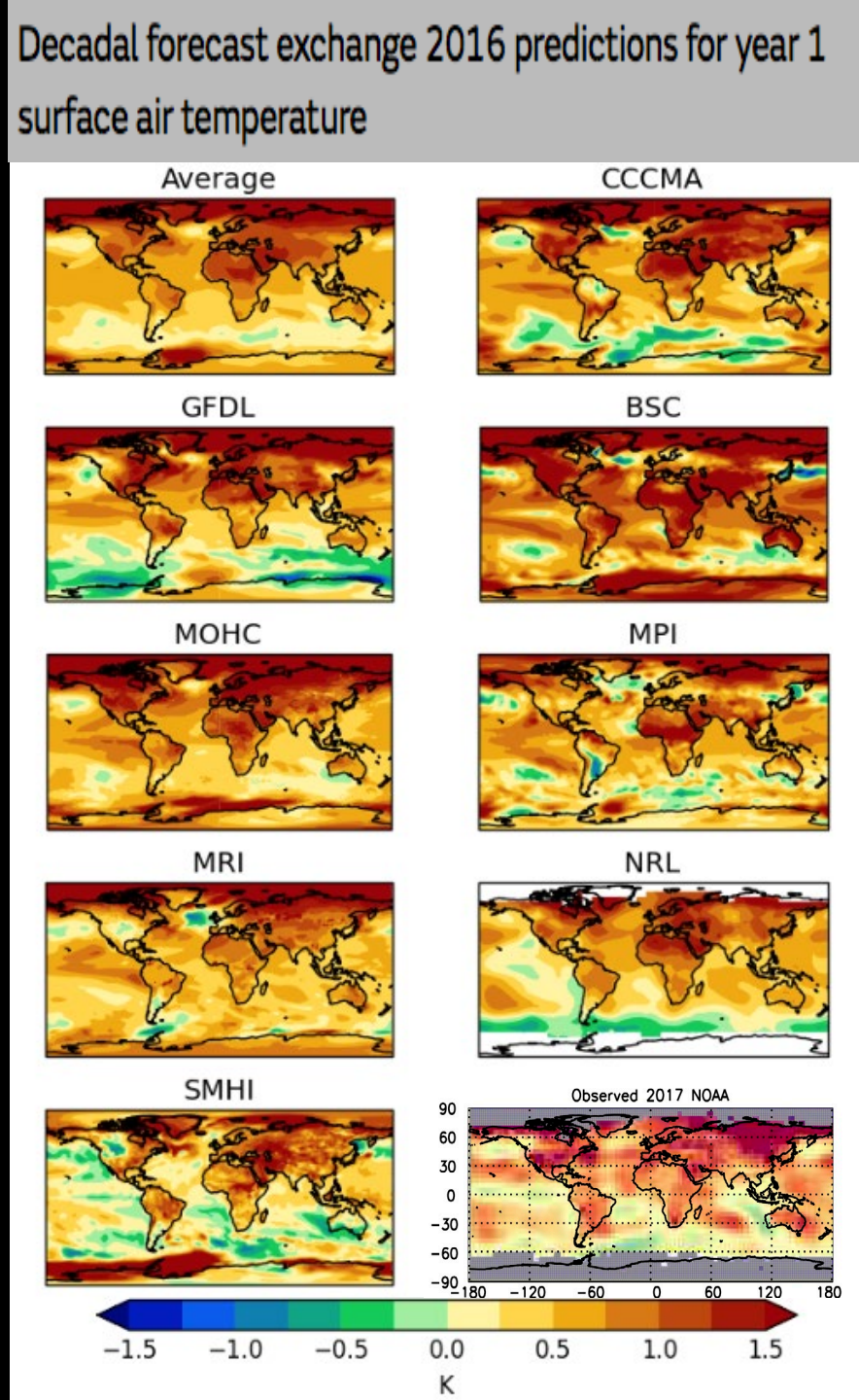
surface temperature deviations from known influences track Arctic sea ice area, lagged 3-5 months

International Climate Forecast "Decadal Exchange"

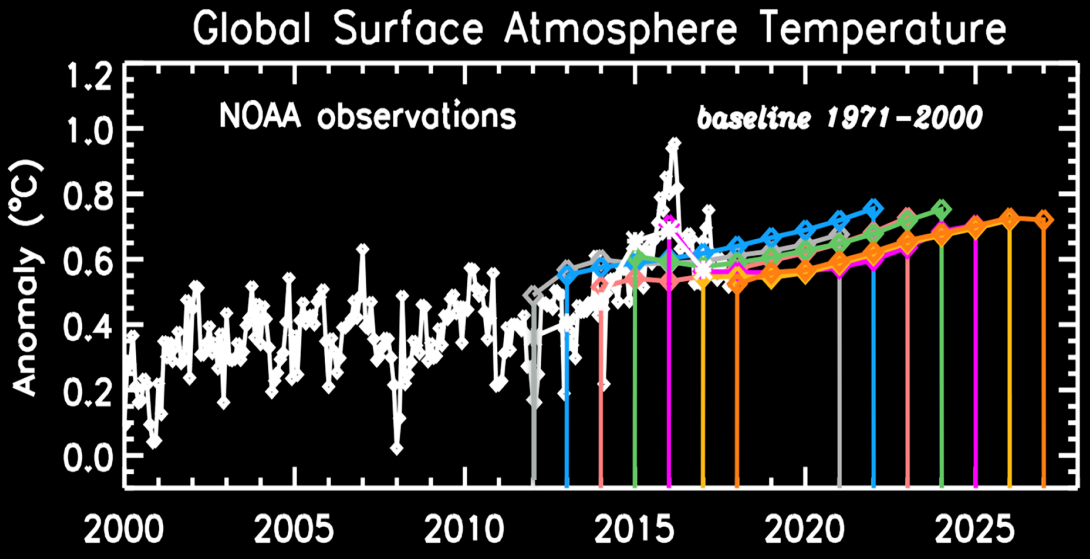
- projections of annual global and regional surface temperature for next 10-years have been made every year since 2012
  - 7 years so far
- Initiated in 2011 by UK Met. Office Hadley Center, to maintain climate modelling capability developed for IPCC
  - Smith et al, Clim. Dynam., 2012
- *Recently endorsed as an official WMO program*

WORLD METEOROLOGICAL ORGANIZATION
Weather · Climate · Water

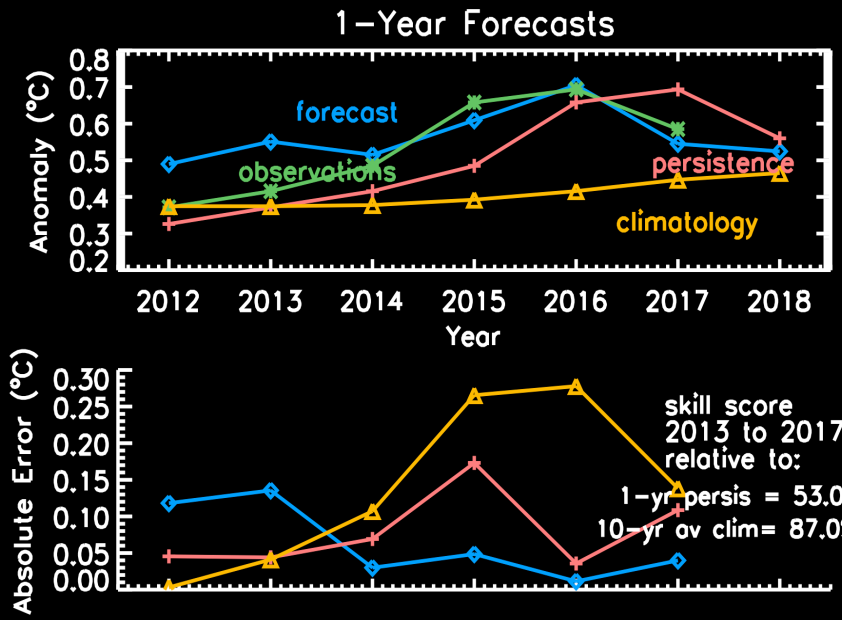
https://www.metoffice.gov. long-range/decadal-uk/research/climate/seasonal-to-decadal/multimodel//

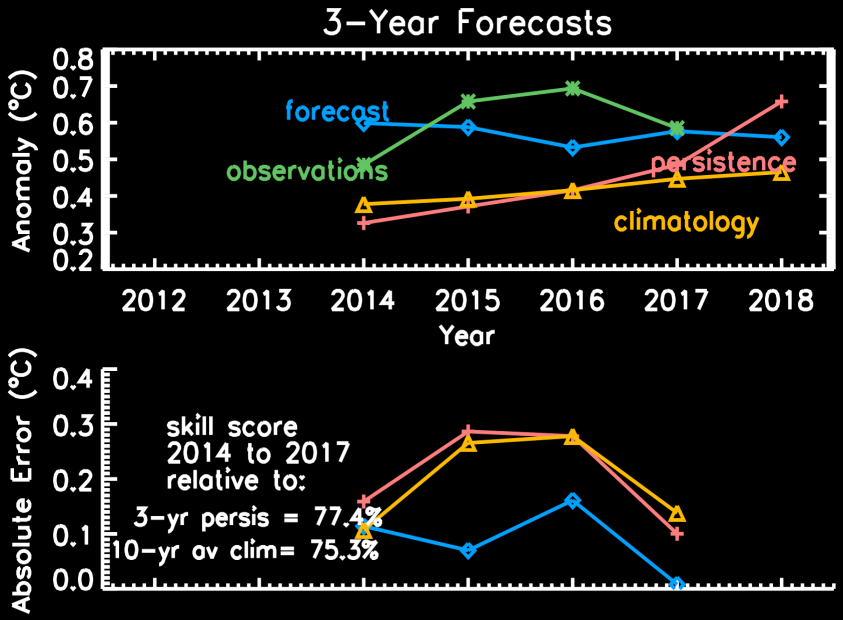


Statistical model projections of (deseasonalized) global SAT made for the "Decadal Exchange"



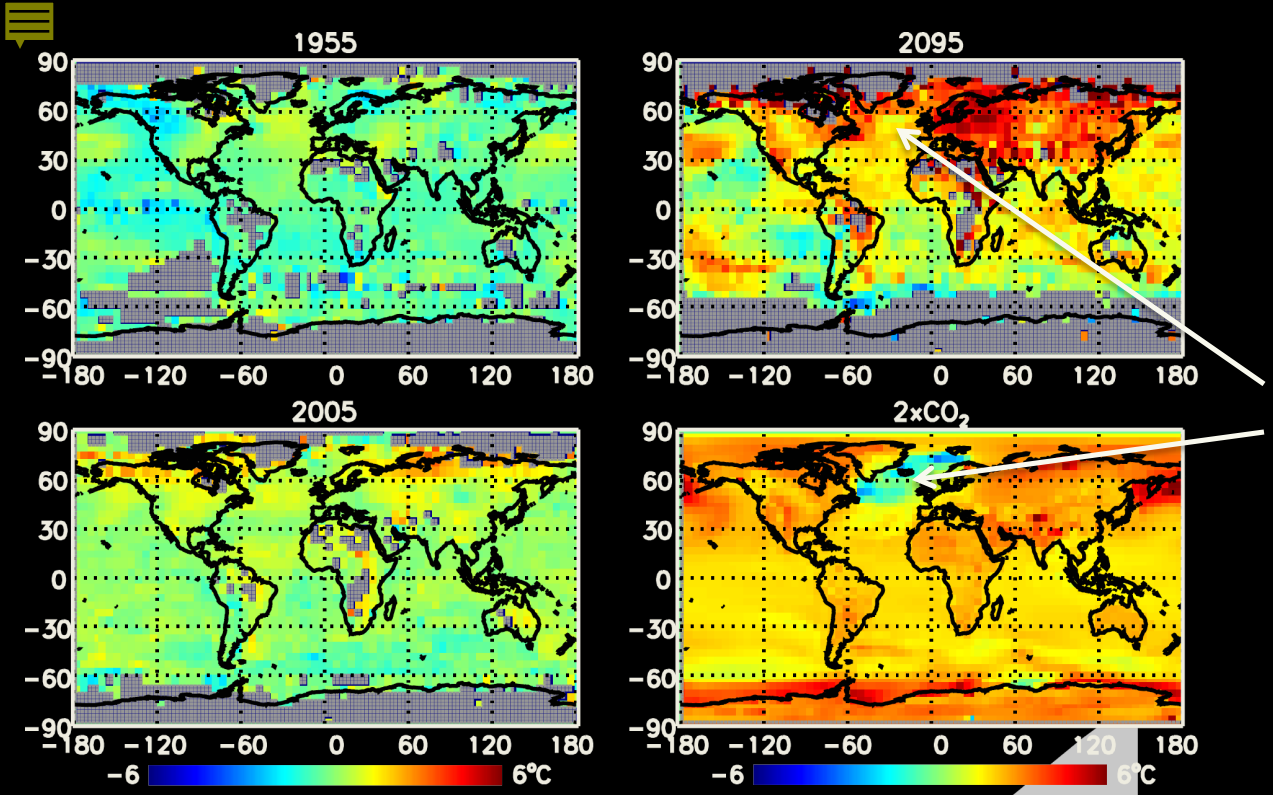
Forecast Skill

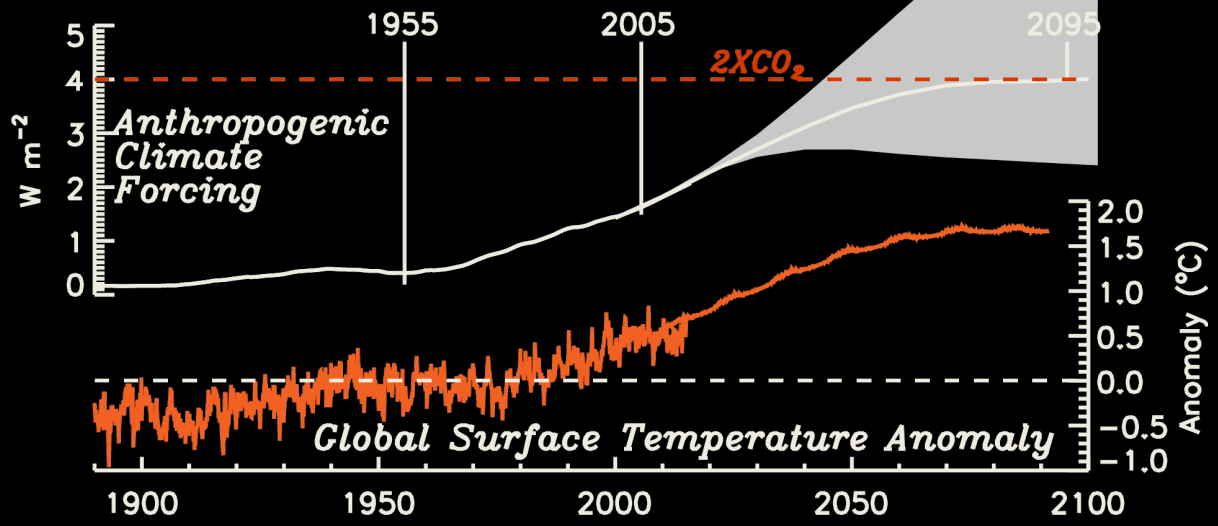




Earth's Surface Temperature in 2100

Statistical extrapolation of measurements suggests more North Atlantic warming than GISS Model 3 projects:





North Atlantic cools

↑

reduces transport of warm tropical water to higher latitudes

↑

deceases strength of Atlantic Meridional Overturning Circulation

↑

GHG surface warming increases fresh water input to North Atlantic

How will the Atlantic Meridional Overturning Circulation Change?

Zickfeld et al., Clim. Change, 2007

Lean, in Climate 2020, UNA-UK, 2015

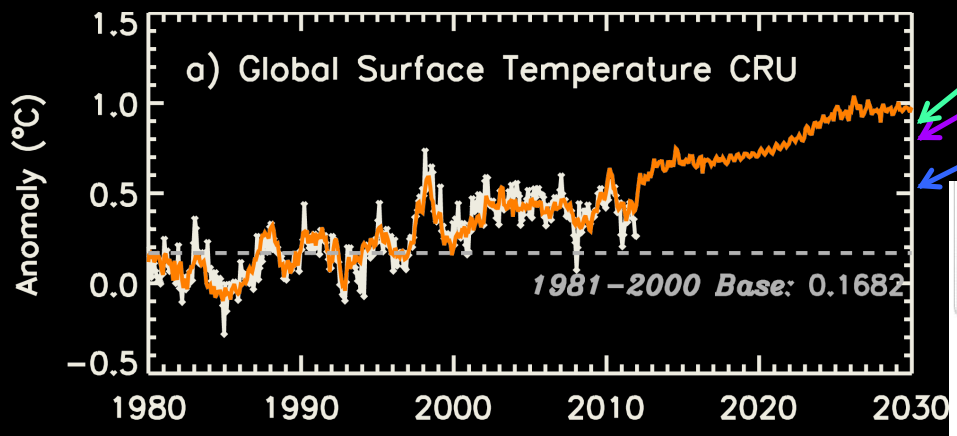
Could a quiet Sun cancel global warming?

If solar irradiance decrease from 2020 to 2030 is:

1X solar cycle ➔ ΔT=-0.1°C

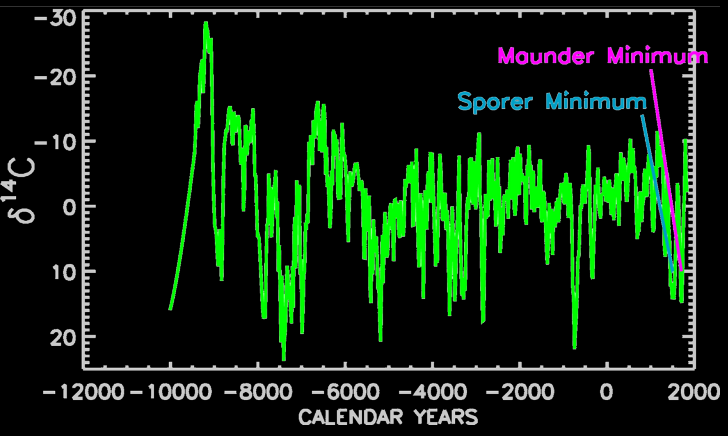
2X solar cycle ➔ ΔT=-0.2°C

5X solar cycle ➔ ΔT=-0.5°C



No: A new Maunder Minimum will NOT cancel global warming, or cause another Little Ice Age….

and it is statistically unlikely for another 2400 years (McCracken & Beer, 2007).



2400-year cycle in clusters of extreme minima in tree-ring ΔC^{14} – solar activity proxy

Capital Weather Gang

The inside scoop on weather in the D.C. area and beyond

The Washington Post Weather website | Jump to CWG's Latest Full Forecast | Outside now? Radar, temps and more: Weather Wall

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AT A GLANCE

Fri	Sat	Sun
---	---	---
-- | 48	32 | 46	30 | 43
Mon	**Tue**	**Wed**
---	---	30%
27 | 43	29 | 47	32 | 47

Forecast by National Weather Service

RIGHT NOW

DCA | IAD | BWI

National Airport

eather: Overcast

mp: 44.0 F (6.7 C)

ind Chill: 37 F (3 C)

ind: Northwest at 16.1 PH, Gusting to 21 MPH

w Point: 26.1 F

ressure: 1010.2 mb

Mar 1 2013, 10:52 am EST

Posted at 12:04 PM ET, 02/28/2013

Could a quiet sun cancel global warming?

By Jason Samenow

Current solar cycle 24 (the curve on the right) shows fewer sunspot numbers than cycle 23 (on curve on the left) (NASA)

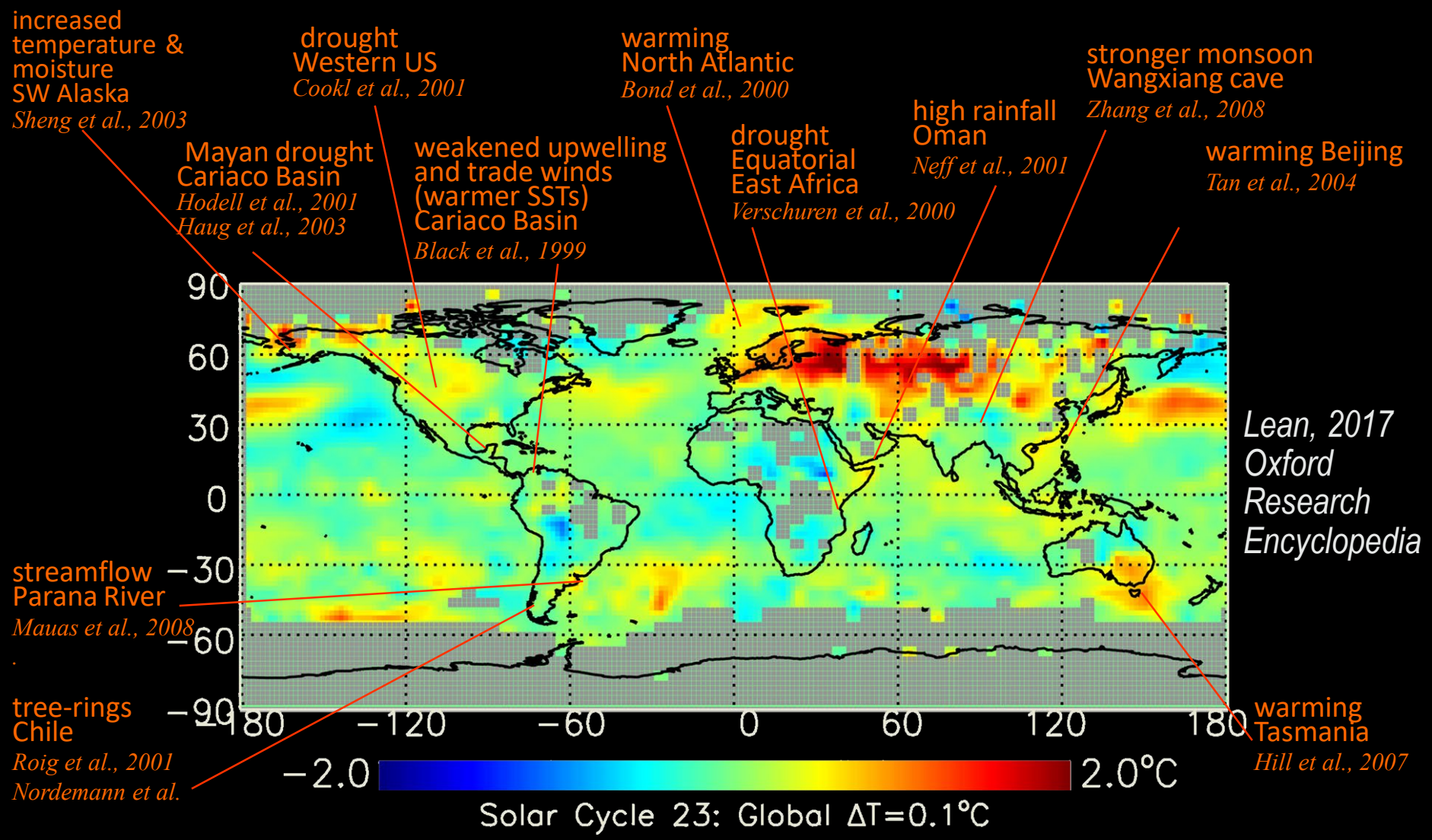
The current solar maximum, the high point in the sun's activity over an 11-year

Modern Climate Change: *Summary*

- Global warming can naturally “pause" or "advance"
  - natural influences mitigate or accelerate ongoing anthropogenic warming
- 2016 was the hottest year on record
  - strong El Niño & modest solar increase, superimposed on anthropogenic warming
- Observations, Models – can we trust them?
  - different surface & space-based temperature records agree
  - physical climate models can't replicate natural decadel variability
- If global warming is real, why is it so cold?
  - greenhouse, solar & volcanic radiative forcings alter thermal gradients which drive dynamical responses
- What to expect in the future
  - anthropogenic warming, natural warming and cooling
  - emerging tipping points?

Paleo Sun–climate synopsis

…when solar activity is high….



significant local changes do not imply global changes of equal magnitude

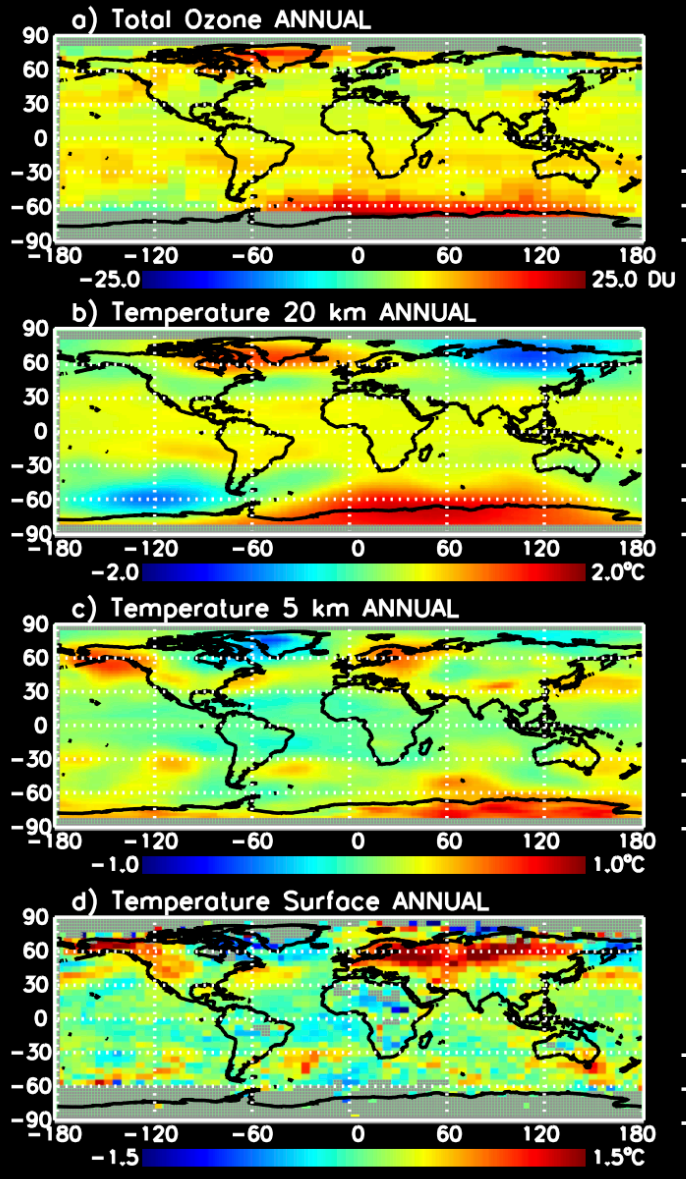
Comparisons with statistical solar forcing responses can help improve climate models

Schneider (1977):

"A knowledge of the terrestrial climate response to a known solar variation could provide a gauge against which climate models could be calibrated. These models, in turn, are the only tools available for society to estimate the seriousness of the growing influences human activity may have on climate.."

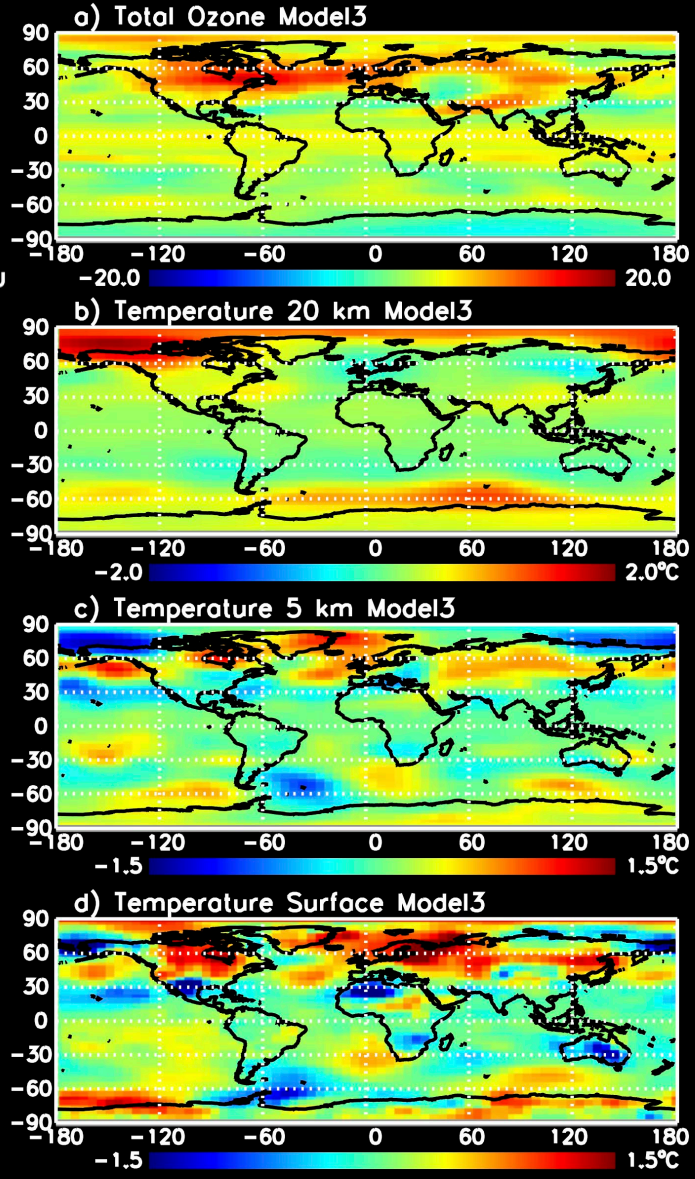
Statistical Model of Observations

Lean, ORE, 2016



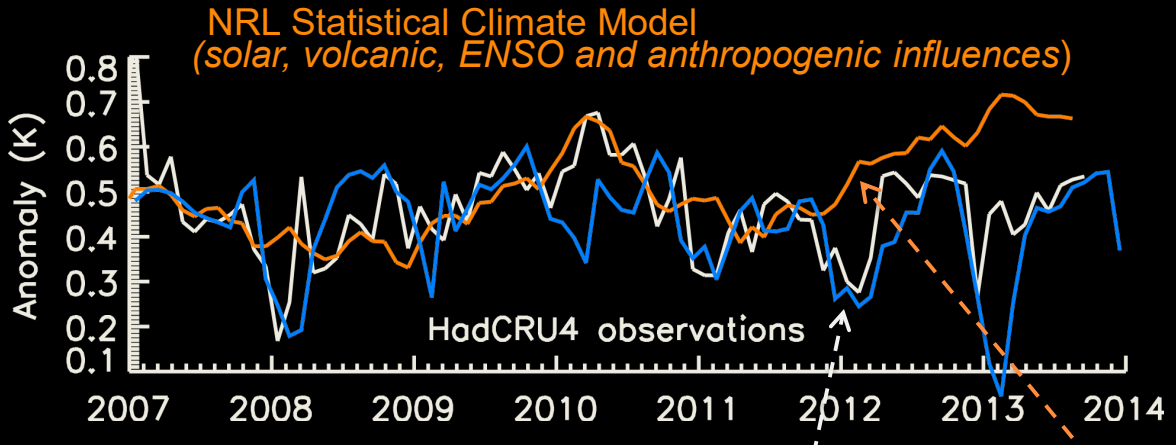
GISS Model3 Physical Climate Model

Rind et al., JGR, 2008



Very Recent Climate Change

Global Surface Temperature



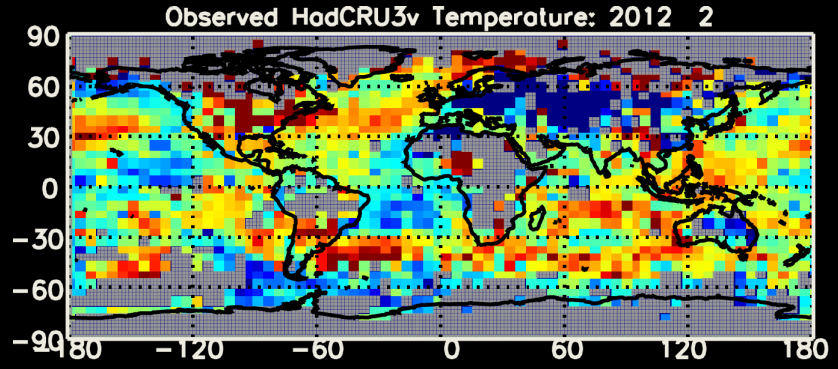
surface temperature deviations from known influences track Arctic sea ice area, lagged 5 months

BASC Workshop, Sept 2013:
Linkages between Arctic Sea Ice Loss and Mid-Latitude Weather Patterns

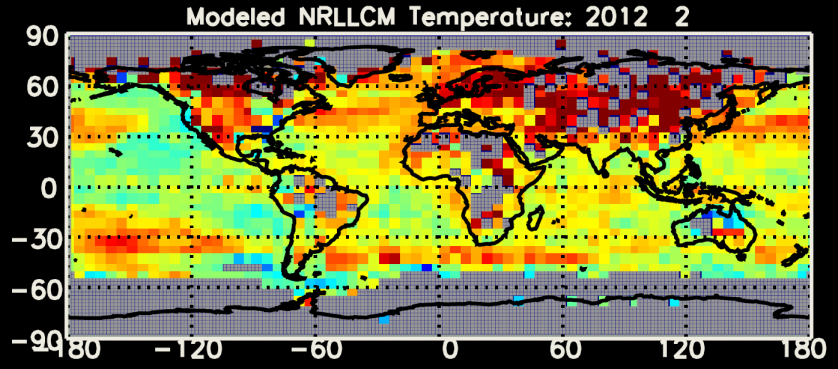
- *surface warming*
- ➔ *melting Arctic Ice*
- ➔ *darker surface, increased open water*
- ➔ *increased solar absorption*
- ➔ *altered mid-to-high latitude thermal gradients*
- ➔ *altered circulation patterns*
  e.g. Overland & Wang, 2010
- ➔ *NH mid lat winter cooling*
- ➔ *negative global temperature feedback?*

Regional Surface Temperature

Feb 2012: Observed



Feb 2012: Statistical Model



Regional Temperature Change: Lower Stratosphere

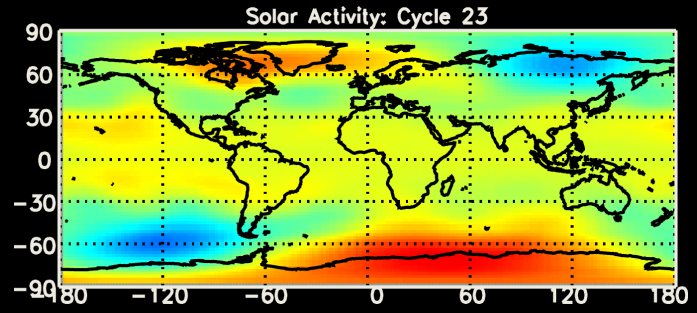
only 13 "hi-top" climate models in IPCC's ~40 models

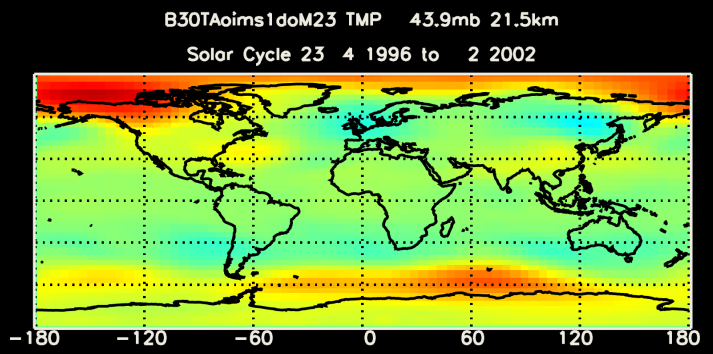
Determined Statistically from Observations

Modeled with GISS Model 3

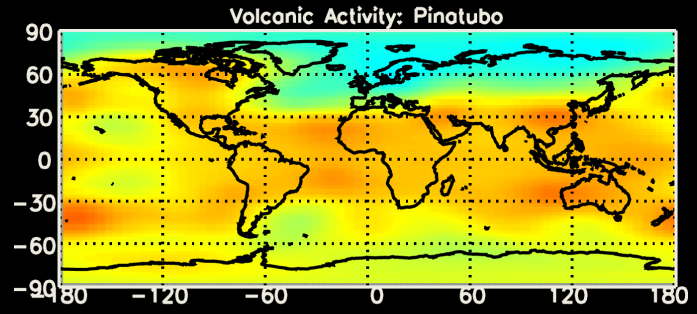
Rind et al., JGR, 2008

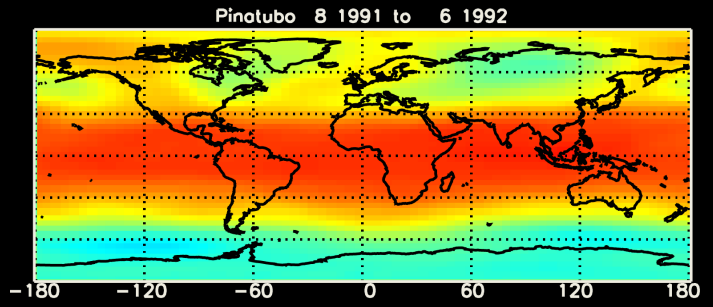
Solar Activity



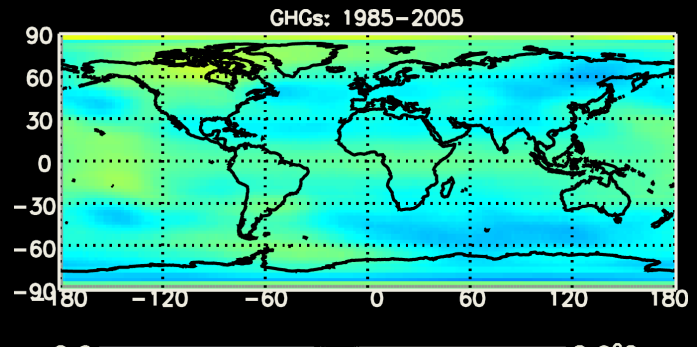


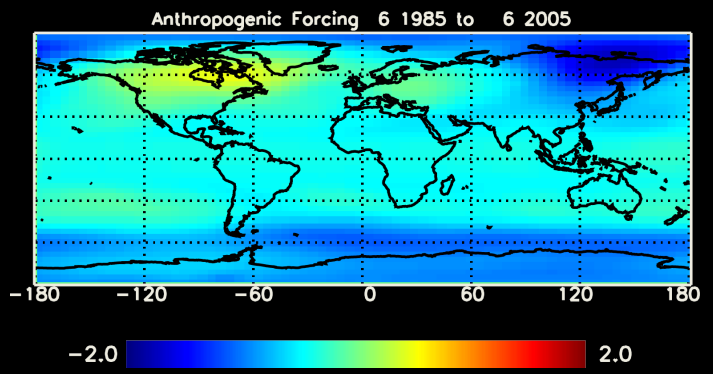
Volcanic Activity



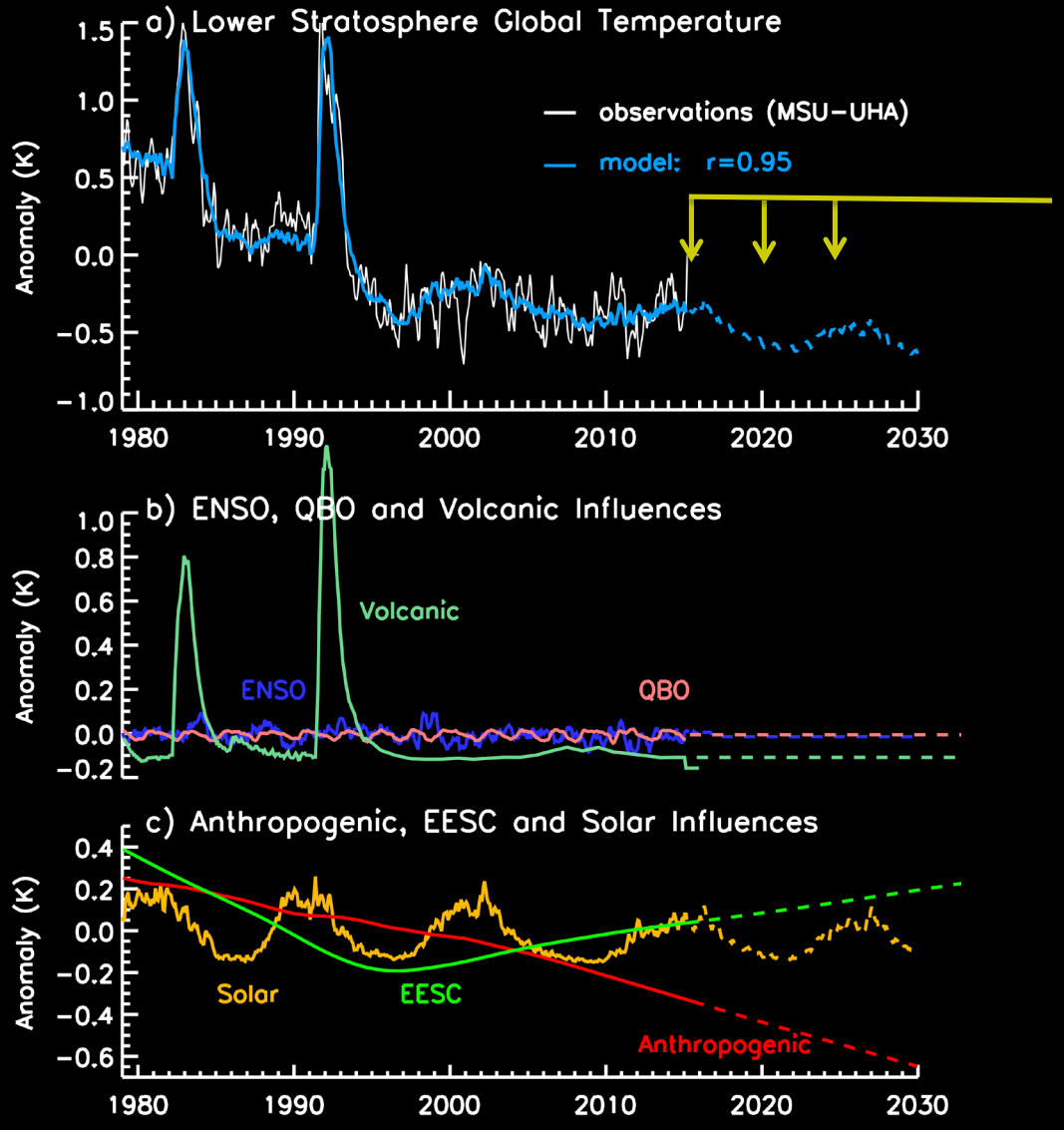


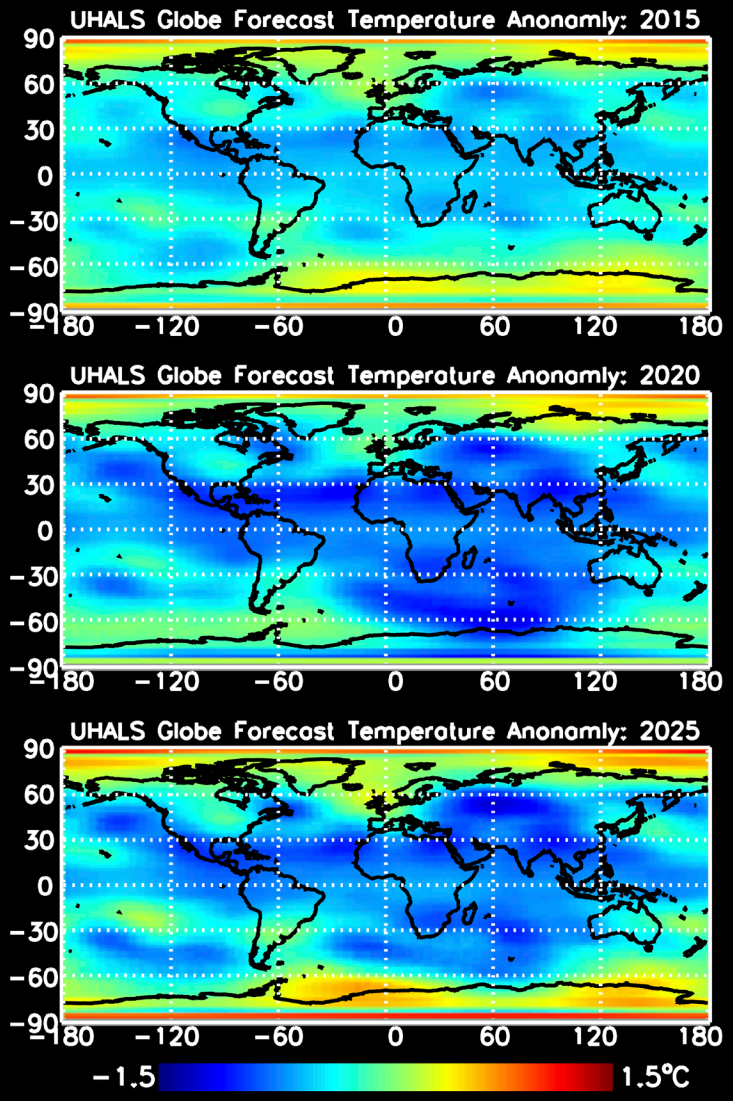
Greenhouse Gases





Middle atmosphere temperature projections



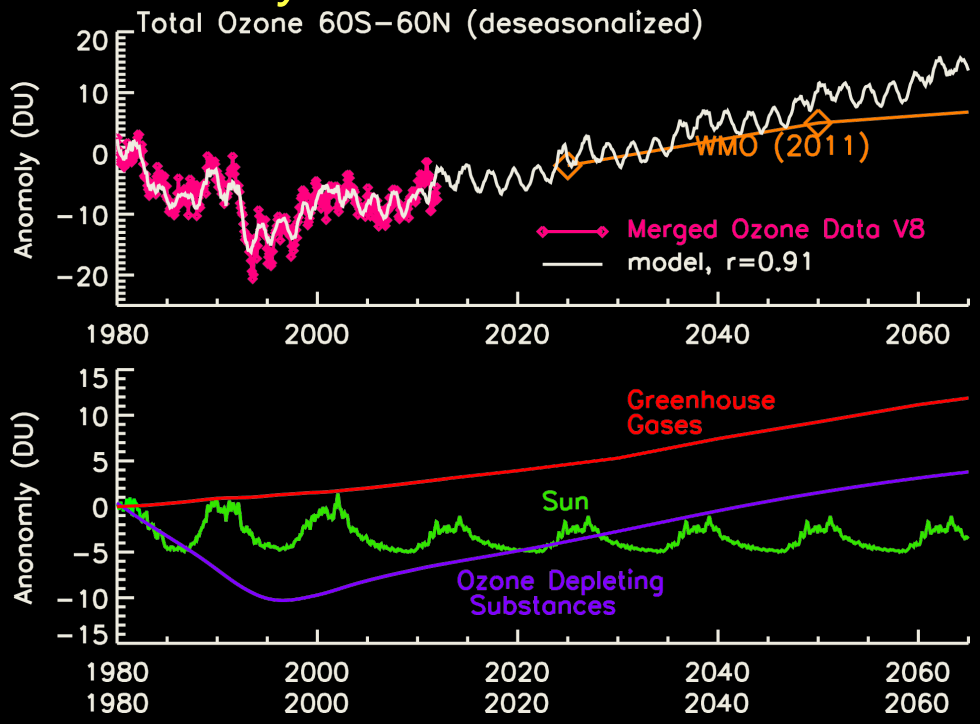


When – and Will? - the Ozone Layer Recover?

… when will ozone recover from chlorofluorocarbon depletion?

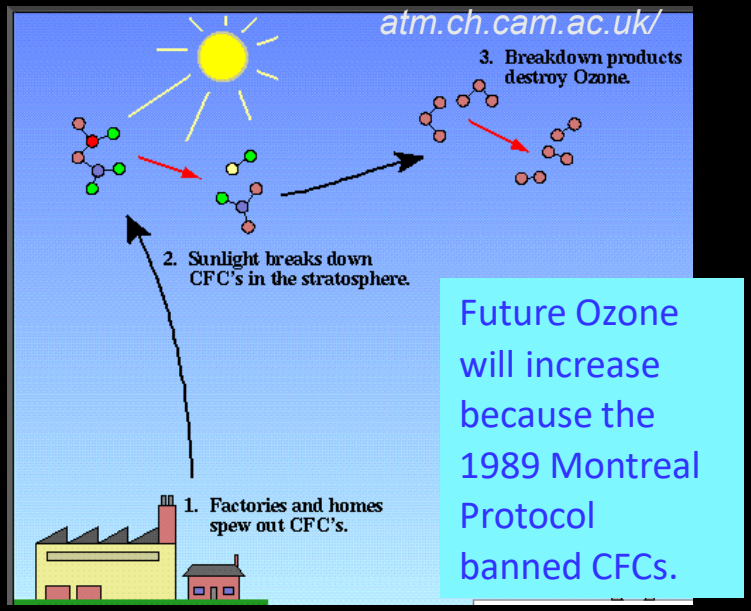
… how will surface warming affect ozone?

… how will ozone evolve in the twenty first century?



NOTE: Merged Ozone Datasets V8 and V8.6 yield very different projections of total ozone in the 21st century…calibration effects in V8.6?

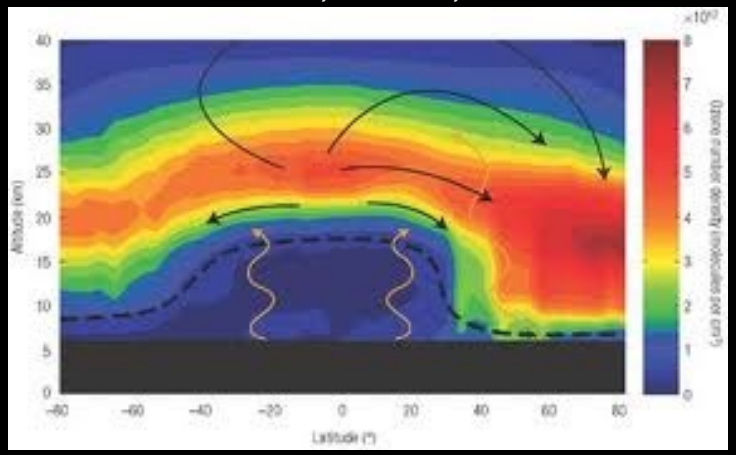
Lean, JAS, 2014



Future Ozone will increase because the 1989 Montreal Protocol banned CFCs.

Future ozone will also increase because greenhouse gases cool the ozone layer, which increases chemical ozone production, and warm the lower atmosphere, which alters circulation…

Rind et al., J. Clim., 1998



Statistical separation of the causes of recent surface temperature variability